

# Naval Surface Warfare Center Carderock Division

West Bethesda, MD 20817-5700

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NSWCCD-TR-98/005 April 1997

Survivability, Structures, and Materials Directorate

Technical Report

## Development of HWAM $\text{Li}_x\text{CoO}_2$ Reserve Battery

by

Charles J. Kelly (Alliant Techsystems, Inc.)

Edited by Charles W. Fleischmann (Advanced Technology & Research Corporation)

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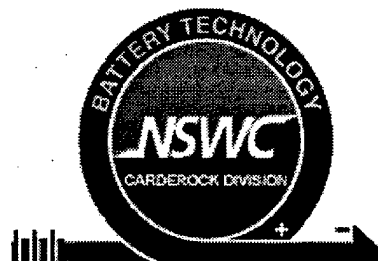
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## Contents

	<i>Page</i>
Introduction .....	1-1
Requirements .....	2-1
Alliant Techsystems, Inc. Battery Design Development Philosophy.....	3-1
Process Development .....	4-1
Test Results .....	5-1
Preprogram Testing .....	5-1
Fixtured Cell Testing at Environmental States.....	5-7
Hermetic Cell Performance Testing at Environmental States .....	5-18
Hermetic Cell Safety Testing.....	5-26
Studies .....	6-1
Cell Improvement Studies.....	6-1
Li <sub>0.5</sub> CoO <sub>2</sub> Comparison with SOCl <sub>2</sub> .....	6-3
Battery Life Expectancy.....	6-4
HWAM Active Li/Li <sub>0.5</sub> CoO <sub>2</sub> Battery.....	6-4
Li/Li <sub>0.5</sub> CoO <sub>2</sub> Capacity Not Lost to Depassivation Requirements.....	6-20
Unit Price Cost Estimate for HWAM Reserve Battery .....	6-21
References .....	7-1
Appendices	
A--HWAM Drawing Package.....	A-1
B--U.S. Patent No 5,667,660: Synthesis of Charged Li <sub>x</sub> CoO <sub>2</sub> (0<x<1) for Primary and Secondary Batteries.....	B-1
C--Compilation of Hermetic Cell Test Results .....	C-1
D--Safety Study Presentation of July 20, 1995.....	D-1
E--Specification Sheets for Ordnance Batteries.....	E-1
Distribution.....	(1)

<i>Number</i>	<i>Figures</i>	<i>Page</i>
1-1	Reserve Battery Outline and Interface.....	1-2
2-1	HWAM Activation Time Requirements .....	2-2
2-2	HWAM Power Profile.....	2-3
4-1	Block Diagram of Charging Process for $\text{Li}_{0.5}\text{CoO}_2$ and Subsequent Fabrication and Testing of a Cell .....	4-2
4-2	Discharge Tests of Low Rate Charged $\text{Li}_{0.5}\text{CoO}_2$ .....	4-3
4-3	Discharge Test.....	4-4
5-1	Picatinny Cell Modified with a Precharged $\text{Li}_{0.5}\text{CoO}_2$ Cathode .....	5-3
5-2	Storage and Test Matrix for Option 7, Picatinny Cell (Modified with $\text{Li}_{0.5}\text{CoO}_2$ Cathodes).....	5-4
5-3	Fresh Discharge Performance of Picatinny Reserve Cell in Small Hermetic Hardware (Modified Picatinny Cell 99275567) .....	5-5
5-4	Subcell No. 103 of HWAM Type, Reserve Battery Design, Using Precharged $\text{LiCoO}_2$ Cathode and Cycled after First Discharge at the Indicated Rates .....	5-6
5-5	HWAM Single Cell Hardware Test Fixture.....	5-9
5-6	HWAM Anode Assembly - Lithium Foil Press and Trim .....	5-9
5-7	HWAM Cathode Assembly Installation.....	5-10
5-8	HWAM Assembled Cell Stack .....	5-10
5-9	Pulse and Capacity Rundown Profile, Cell WAMF06.....	5-12
5-10	Pulse profile of (4) 3.5 Amp, 0.5 Second Duration at Beginning of Life .....	5-13
5-11	No Load Voltage Rise Time ( $T_R$ ).....	5-14
5-12	Fixtured Cell Test Profile.....	5-15
5-13	Pulse and Capacity Discharge Profile, Cell WAMF11 .....	5-16
5-14	Erect Pulse, 8 Seconds After Activation, (WAMF12) .....	5-17
5-15	Individual Cell Case .....	5-20
5-16	HWAM Battery .....	5-21
5-17	Pulse and Capacity Discharge Profile, Cell WAMH05.....	5-22
5-18	Pulse and Capacity Discharge Profile, Cell WAMH20.....	5-23
5-19	Pulse and Capacity Discharge Profile, Series Test.....	5-24
5-20	Pulse and Capacity Discharge Profile, Cell WAMH07.....	5-25
5-21(a/b)	External Short Circuit Test, Cell WAMH08.....	5-27
5-22(a/b)	External Short Circuit Test, Cell WAMH22.....	5-29
5-23	Internal Short Circuit Test and Capacity Discharge Profile, Cell WAMH09 ..	5-31
5-24(ab/c)	Short Circuit and Cell Reversal Test, Cell WAMH18 .....	5-32
5-25	Abuse Test, Activated with 10% Electrolyte, WAMH06 .....	5-35
6-1	Separator Evaluation, +75°F .....	6-5
6-2	Separator Evaluation, +28°F .....	6-6
6-3	Separator Evaluation, 0°F .....	6-7
6-4	Separator Evaluation, -25°F .....	6-8
6-5	Modified Picatinny Cell 9275567, $\text{Li/Li}_x\text{CoO}_2$ /DSMF, 1 Layer Veretek.....	6-9
6-6	Modified Picatinny Cell 9275567, $\text{Li/Li}_x\text{CoO}_2$ /DSMF, 1 Layer Veretek .....	6-10

**Figures (Cont.)**

<i>Number</i>		<i>Page</i>
6-7	Modified Picatinny Cell 9275567, Li/Li <sub>x</sub> CoO <sub>2</sub> /DSMF, 1 Layer Veretek .....	6-11
6-8	Modified Picatinny Cell 9275567, Li/Li <sub>x</sub> CoO <sub>2</sub> /DSMF, 1 Layer Veretek .....	6-12
6-9	Cell Capacity Versus Cutoff Voltage .....	6-13
6-10	Normalized Power Curves for Li/Li <sub>0.5</sub> CoO <sub>2</sub> and Li/SOC1 <sub>2</sub> .....	6-14
6-11	Power Output Comparison Between Li/Li <sub>0.5</sub> CoO <sub>2</sub> and Li/SOC1 <sub>2</sub> .....	6-15
6-12	Fast Run Down Versus Slow Run Down of Picatinny Hermetic Cells, Picatinny #9275567 (Modified), Room Temperature .....	6-17
6-13	HWAM Active Battery Design .....	6-18
6-14	HWAM Reserve Battery, 30 Ampere-Hour Capacity .....	6-22

**Tables**

<i>Number</i>		<i>Page</i>
2-1	Form and Function Requirements .....	2-1
4-1	Fabrication Data for Charging Cells Li <sub>0.5</sub> CoO <sub>2</sub> Material .....	4-5
5-1	Modified Picatinny 9275567 Cells with Precharged Cathodes LiCoO <sub>2</sub> Stored in Reserve State (6 months) .....	5-7
5-2	HWAM Fixtured Cell Test Data at Room Temperature .....	5-11
6-1	Physical Comparisons .....	6-2
6-2	Capacity Comparison between Li/Li <sub>0.5</sub> CoO <sub>2</sub> and Li/SOC1 <sub>2</sub> in Same Size Hermetic Cells .....	6-16
6-3	HWAM Active Battery Electrode Design .....	6-23
6-4	HWAM Active Battery Weight Summary .....	6-23

## Preface

Contract No. N60921-93-C-0060, Option 7, awarded to Alliant Techsystems, Inc. by the Naval Surface Warfare Center, and funded by Office of Naval Research, developed large (100 Ah) rechargeable lithium/lithium cobalt oxide cells for batteries to propel undersea vehicles. As built, these cells were in the discharged state because the available precursor cathode material was of the electrochemically-discharged chemical composition. Charged precursor cathode material was not only unavailable, but its chemical stability was unknown and suspect. Obtaining it required development of a preparatory process and an understanding of its handling requirements for cathode manufacture. Recognizing that there could be advantages to building cells in the charged state because the user could put them immediately into service, and that applications needing reserve cells require them, the Navy was pleased to include a development effort to prepare charged precursor cathode material when given the opportunity *via* Army funding. Under Option Item 7 to the contract, the Army (Project Manager for Mines, Countermine, and Demolitions) funded development of charged lithium/lithium cobalt oxide cells to power Hand-Emplaced Wide Area Munitions (HWAM). This effort intended to develop reserve cells, which were also capable of a limited number of charge/discharge cycles, as an alternate to the baseline system, lithium/thionyl chloride, a non-rechargeable battery.

## Chapter 1

### Introduction

The first goal of this program was to conduct a cell and battery design analysis such that the final battery design would comply with the specified weight and specific geometric volume identified in Customer Specification No. 29224A Figure 1-1, Reserve Battery Outline and Interface. This specification is for the Hand-Emplaced Wide Area Munitions (HWAM). To meet the second goal, the battery's unit cell would have its design detailed for eventual demonstration build and test. The battery design analysis was required by contract to include the following key elements:

- design for battery rechargeability,
- battery state-of-charge indication,
- design circuitry to control recharge,
- comparison of the advantages/disadvantages of an internal/external reservoir,
- battery production cost analysis,
- battery environmental issues of manufacture and disposal,
- safety of the battery design and analysis of probability of battery explosion on internal or external short circuit.

The battery design analysis, once completed, was the basis for a detailed cell design. The cell design was documented by a drawing package. Revision updates to the drawing package resulted from the contract-required execution of cell fabrication and testing. The final drawing package is given as Appendix A. The cell development process was one of verification by experiment of key concerns regarding form factor, reserve capability, rate, and environmental limits for an advanced electrochemistry, namely, lithium/lithium cobalt dioxide ( $\text{Li/Li}_x\text{CoO}_2$ ). The steps were as follows:

- The cell design was evaluated in single-cell, bolt-together test fixtures of a configuration that represented the final cell internal design, except the number of plates per cell were not the same as that anticipated for the final design.
- In a parallel effort, the cell build procedures were optimized, particularly with regard to the synthesis process for manufacturing electrochemically-charged lithium cobalt dioxide for cell cathodes.
- Next, the cell design was demonstrated in single cell test fixtures containing multi-plate electrodes of anticipated full-cell design quantities. Voltage versus discharge rate data obtained from these tests were used to project battery performance for a three-cell, series design at full Hand-Emplaced Wide Area Munitions (HWAM) load requirements.
- Finally, cells were constructed of the final design in hermetically-welded cell cases and tested at the environmental extremes outlined in the contract specification.



SPECIFICATION NO. 29224A

NOTES:

1. TERMINAL STYLE SHALL BE SUITABLE FOR SOLDERING ON NO. 22 AWG WIRE. PIN NUMBERS TO IDENTIFY FUNCTION AND LOCATION ONLY.
2. SURFACE TO BE FLAT WHEN INSTALLED IN A BASE ASSEMBLY FIXTURE WITHIN 0.005 IF MIDSECTION OF SURFACE A BOVS TO THE RIGHT. FLATNESS CONTROL NOT REQUIRED IF MIDSECTION OF SURFACE A BOVS TO THE LEFT AS LONG AS 2.870 DIMENSION IS NOT EXCEEDED.
3. LABEL TO BE LOCATED ON THIS SURFACE SHALL BE MARKED IN ACCORDANCE WITH MIL-STD-130 WITH THE FOLLOWING INFORMATION:  
 SUPPLIER NAME/CAVE  
 TDS NAME/CAVE  
 PART NO. 12900045 ITEM NAME  
 (NAM RESERVE BATTERY) AND  
 AND LOT DATE CODE.

TERMINAL PIN	FUNCTION
1	+12 VDC
2	BATTERY SIGNAL
3	+12 VDC RETURN
4	BATTERY INITIATE RETURN

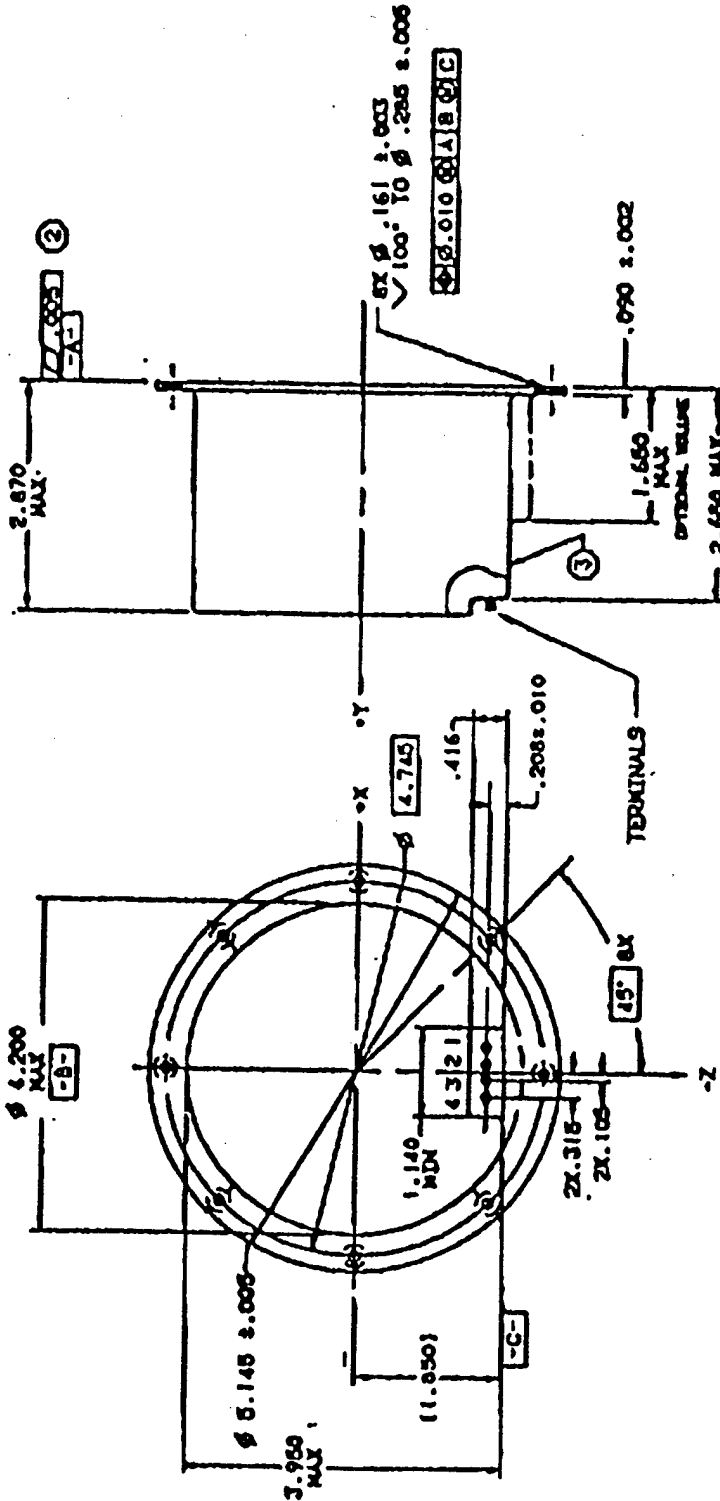


Figure 1-1. Reserve Battery Outline and Interface

## Chapter 2

### Requirements

The battery electrical specifications, physical requirements, and environmental conditions are outlined in Table 2-1. In a similar manner, Figure 1-1 is a reproduction of the HWAM Battery outline drawing from Specification No. 29224A, dated 17 August 1993. This drawing provides all of the interface information needed to mate the battery to the HWAM. Figure 2-1 is also a reproduction from Specification No. 29224A and schematically shows the desired battery activation time for both the hydraulic flow time,  $T_H$  (time for the electrolyte in the battery reservoir to reach the electrode stack), and the electrical rise time,  $T_r$  (time for the battery to come up in voltage from 0 volts to a minimum of 8 volts).

The power demands of the HWAM have a duration of a minimum of 180 days at "Standby" mode prior to device "Arming," followed by up to 30 days in the "Alert" mode, and finally ending on command in a terminal phase of engaging the threat and launch. Details of the power profile are shown in Figure 2-2. Because some use scenarios would benefit if the battery could be cycled a few times, the cycle life was determined.

**Table 2-1. Form and Function Requirements**  
Reference: Spec. No. 29224A, 17 August 1993

<b>Dimensions (Fig. 1-1):</b> - Flange Diameter: - Case Diameter: - Height:	5.145 in max. 4.200 in max. (3.95 in flat side diameter) 2.870 in max.
<b>Weight:</b>	3.0 pounds +0, -0.3 pounds
<b>Leakage:</b>	The battery shall be a hermetically sealed device.
<b>Activation:</b>	Activate in any orientation relative to the local horizontal. Voltage rise time: 0.5 seconds max. to 8.0V (2.67 V/cell) from first detectable voltage.
<b>Voltage and Load:</b> - Maximum Voltage (240 Ma): - Minimum Voltage (240 Ma): - Minimum Voltage for Ordnance Loads (3.75 A):	15.0 volts (5.0 volts/cell) 10.0 volts (3.33 volts/cell) 8.0 volts (2.67 volts/cell)
<b>Capacity:</b> When discharged at a constant load of $400 \pm 10$ Ma, the battery shall maintain a minimum output voltage of 10 volts for the following number of hours:	32.5 hours at 145°F, 13.0 Ah 35.0 hours at 72°F, 14.0 Ah 26.5 hours at -25°F, 10.6 Ah
<b>Temperature - Non Operating:</b> <b>High Temperature - Operating:</b> <b>Low Temperature - Operating:</b>	The battery shall meet the requirements after exposure to temperatures from -50°F to +160°F. The battery shall meet the requirements during exposure to temperatures as high as +145°F. The battery shall meet the requirements during exposure to temperatures as low as -25°F.

SPECIFICATION NO. 29224A

SPECIFICATION NO. 29224A

17 August 1993

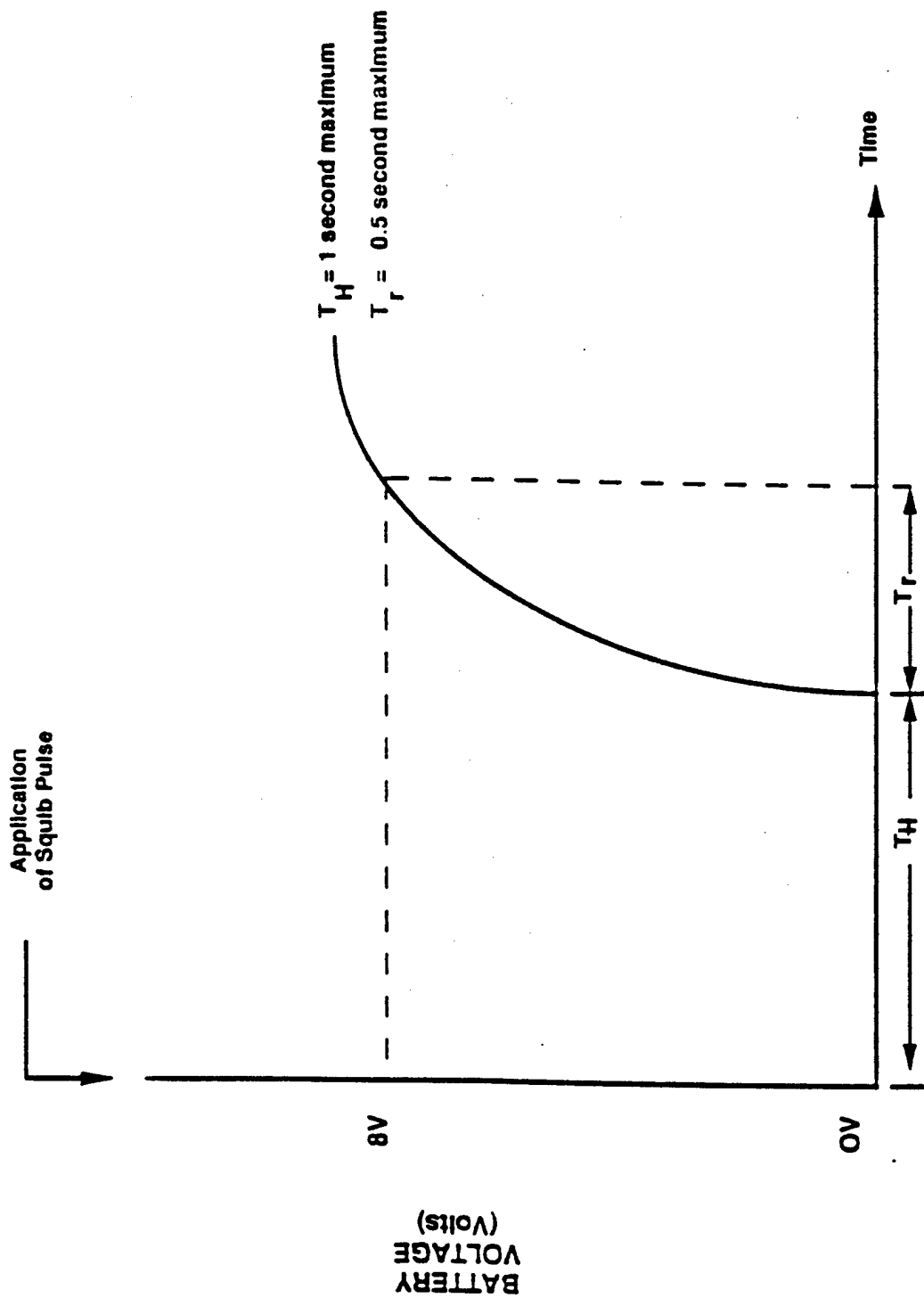
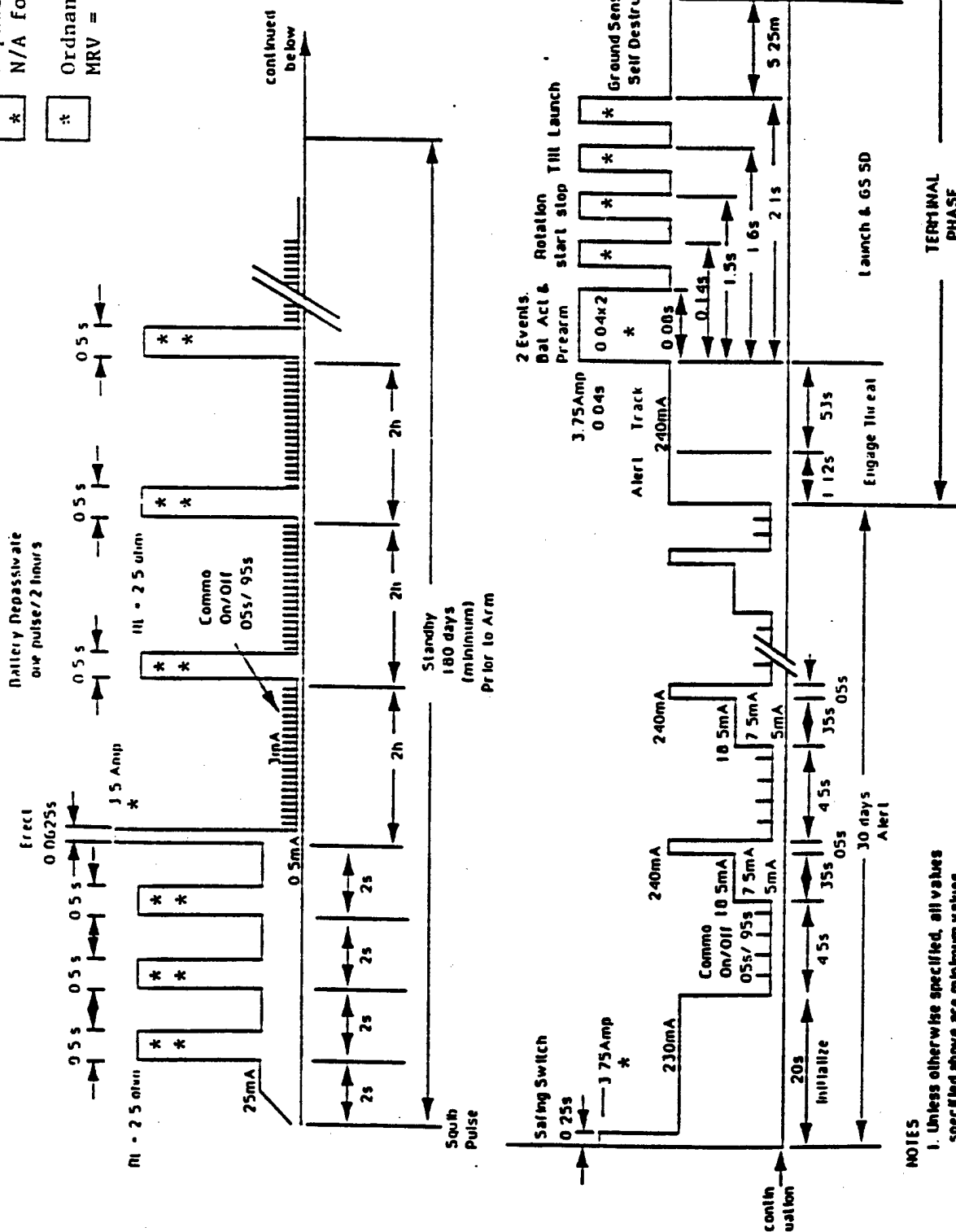


Figure 2-1. HWAM Activation Time Requirements

7 December 1993



### Figure 2-2. HWAM Power Profile

### **Chapter 3**

#### **Alliant Techsystems, Inc. Battery Design Development Philosophy**

The strategy used by Alliant Techsystems, Inc., to develop a safe design for the HWAM power source contained the following key criteria:

- Separation of the three cells required for the voltage demand. Each cell is an hermetically sealed unit that remains electrically and electrochemically isolated over the 210 day minimum active life.
- Selection of an electrochemistry that is innately safer than the baseline system, lithium thionyl chloride; specifically, lithium/lithium cobalt oxide, which has the capability of high energy density and benign short circuit behavior.
- The electrochemistry must also be capable of reserve battery function. Lithium/lithium cobalt dioxide was further developed during this program to demonstrate reserve capability. A complete scale-up process for synthesizing electrochemically-precharged lithium cobalt dioxide was achieved.
- Maximize electrode surface area as a means of lowering the discharge rate to a conservative value, affording long battery Standby and Alert mode life.
- Design electrode shape to facilitate an overall battery structure that would conform to the envelope constraints of the HWAM Reserve Battery Outline and Interface as defined in Specification No. 29224A and shown in Figure 1-1 in this report.
- Design of a safety vent to release internal pressure should an abnormal pressure level occur. Note: During safety tests, an internal, built-in short circuit and externally applied short circuits did not result in sufficient internal pressure to open rupture-type diaphragm vents.

## Chapter 4

### Process Development

Rechargeable  $\text{Li}/\text{Li}_x\text{CoO}_2$  cells are built<sup>1,2</sup> using  $\text{LiCoO}_2$  as the active cathode material (*i.e.*, the  $x$  value in  $\text{Li}_x\text{CoO}_2$  is unity). Cells are cycled by charging from the composition where  $x$  is unity to a value of  $x$  about 0.5. Therefore, when  $x = 1$ , the cell is in the discharged state. That state is employed for fabrication because it is commercially available, and it can be handled under ambient conditions.

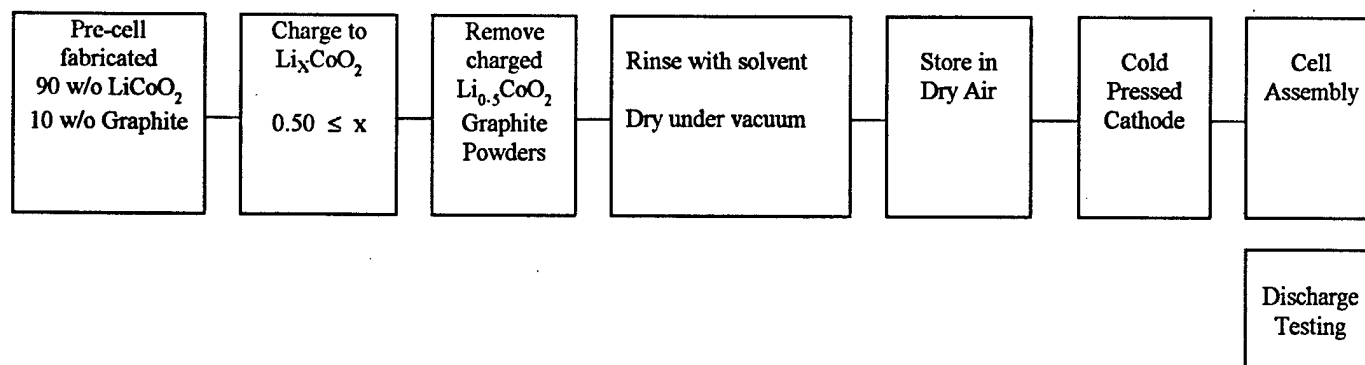
When a reserve primary cell is required, as is the case for the HWAM application, the cell must be ready to discharge immediately upon activation. Therefore, the cell must be built in the charged state. For  $\text{Li}/\text{Li}_x\text{CoO}_2$  cells, this means the cathode must be of the composition  $\text{Li}_{0.5}\text{CoO}_2$ . At the beginning of the development work on the HWAM battery, it was not known if the charged material could be synthesized chemically. Obviously, it could be synthesized electrochemically, within the cell as that occurs during each charge cycle. Nevertheless, it was not known if that material was stable outside the cell, or if it could be reprocessed into a cathode after electrochemical preparation and still maintain its state of charge.

Additionally, this positive electrode material had to be producible in quantities sufficient to meet production quantities of HWAM units. Experimentation proved that the only successful method of synthesizing charged  $\text{Li}_x\text{CoO}_2$  was electrochemical. For this technique, a "Charging Cell" is fabricated without binder in the cathode. In this cell, the composition\* of the cathode mix was 90 percent  $\text{LiCoO}_2$  and 10 percent carbon. After charging, the "charged"  $\text{Li}_{0.5}\text{CoO}_2$  mix is removed, rinsed, and dried for later fabrication into HWAM cathodes of particular shape and area. The fabrication was sufficiently novel to be patented.<sup>3</sup> The patent (Appendix B) provides additional details of the synthesis technique as well as amplifying its advantages. One notable advantage is the ability to employ stainless steel rather than aluminum as the current collector. A cell composed of these cathodes is then capable of storage in the dry state for an indefinite period of time (estimated at 20 years). A cell of such construction, with lithium metal anodes, is a reserve cell until electrolyte is supplied from a reservoir. The baseline electrolyte for these cells was 2-molar lithium hexafluoroarsenate with 0.4-molar lithium tetrafluoroborate ( $2M \text{LiAsF}_6 + 0.4M \text{LiBF}_4$ ) in methyl formate. Alliant uses the acronym DSMF for this electrolyte, for "Double Salt Methyl Formate." An alternate solvent, methyl acetate, was also evaluated as its cost is lower than the formate. This solvent, with the same salts, is called DSMA in the report. An alternate, using this solvent and only the hexafluoroarsenate salt is called SSMA to represent "Single Salt Methyl Acetate."

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\*All percentages are by weight unless otherwise indicated.

A block diagram of the cathode fabrication process is shown in Figure 4-1. During process development, both the size of the Charging Cell, and the rate of charge were increased, adding significantly to the scaled-up yields. Figures 4-2 and 4-3 show that a progression of charge rate increase had no effect on the discharge capacity of quality control cells used to verify charged  $\text{Li}_{0.5}\text{CoO}_2$  material performance. The number of Charging Cells built during this program and their respective data are shown in Table 4-1.



**Figure 4-1. Block Diagram of Charging Process for  $\text{Li}_{0.5}\text{CoO}_2$  and Subsequent Fabrication and Testing of A Cell.**

# H-WAM PRECHARGED CATHODE LOT WAMPC10

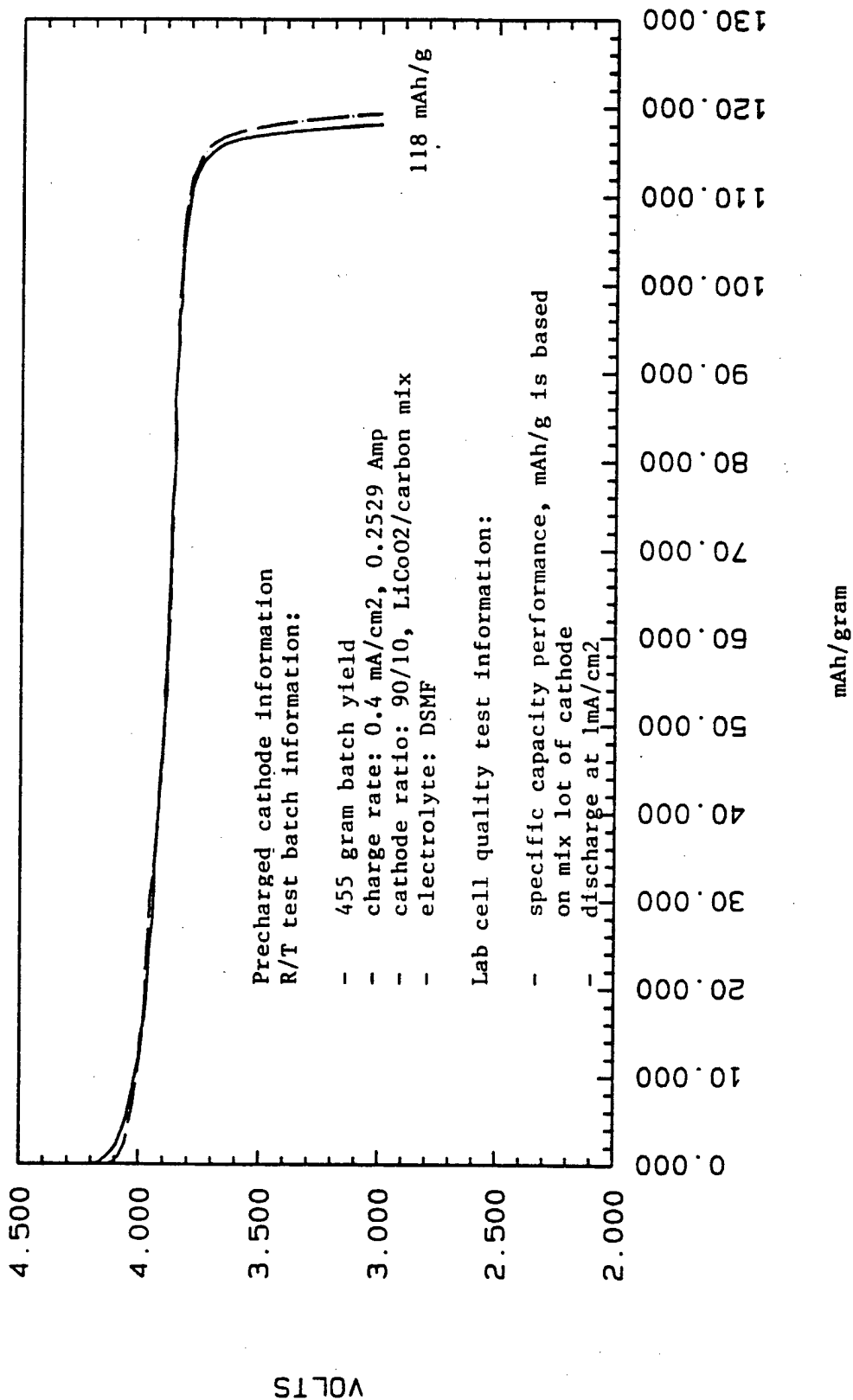


Figure 4-2. Discharge Tests of Low Rate Charged Li<sub>0.5</sub>CoO<sub>2</sub>



## H-WAM PRECHARGED CATHODE LOT WAMPC32

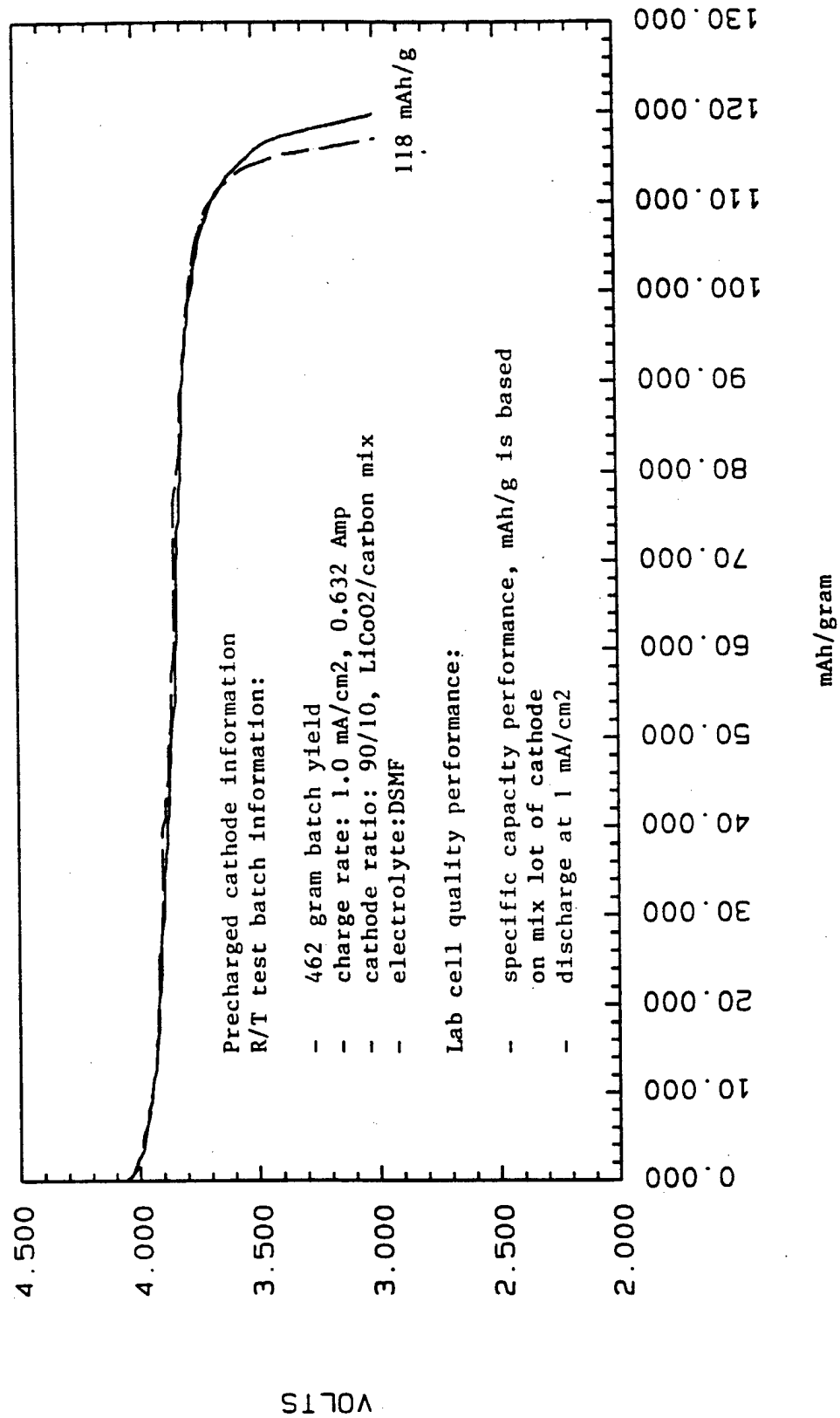


Figure 4-3. Discharge Test

Table 4.1. Fabrication Data for Charging Cells  $\text{Li}_{0.5}\text{CoO}_2$  Material

**H-WAM**  
**Precharged Cathode Information**

CELL NUMBER	LCoO <sub>2</sub> Manufacturer	Manufacture's lot Number	LiCoO <sub>2</sub> Grade	Cathode Weight grams	Theoretical Capacity Ah 0.55 F/M*	Charge rate mA/cm <sup>2</sup>	BEFORE CHARGE		Test results After Charge				Lab Cell Evaluation 1 mA/cm <sup>2</sup>	
							AC Imped. milli- ohms	OCV***	Capacity (Ah)	End Voltage	AC Imp. milli- ohms	OCV After 24 hrs	OCV before Discharge	Average 2 cells mAh/gram**
WAMPC06	FMC	501-01-WBE-003	Battery	449.20	60.881	0.4	186	3.437	60.881	4.257	140	4.237	4.288	121.49
WAMPC07	Johnson Matthey	F08C06	Industrial	388.70	52.681	0.4	180	3.694	52.681	4.305	100	4.252	4.310	110.24
WAMPC08	FMC	501-01-WBE-003	Battery	474.90	71.515	0.4	200	3.593	71.520	4.095	50	4.025	4.085	90.70
WAMPC09	FMC	501-01-WBE-003	Battery	465.40	70.085	0.8	160	3.582	70.090	4.217	32	4.136	4.156	111.51
WAMPC10	FMC	501-01-WBE-003	Battery	455.25	61.700	0.4	120	3.64	61.700	4.245	30	4.226	4.283	118.78
WAMPC12	FMC	501-01-WBE-003	Battery	426.87	57.854	0.4	110	3.644	57.854	4.266	50	4.234	4.267	120.72
WAMPC13	FMC	501-01-WBE-003	Battery	390.87	52.972	0.4	115	3.560	52.972	4.212	48	4.163	4.200	114.14
WAMPC14	FMC	501-01-WBE-003	Battery	450.70	61.079	0.4	145	3.545	61.079	4.288	32	4.159	4.092	115.41
WAMPC15	FMC	501-01-WBE-003	Battery	443.50	60.110	0.4	145	3.520	60.110	4.189	28	4.087	4.037	102.01
WAMPC16	FMC	501-01-WBE-003	Battery	464.61	62.969	0.4	100	3.590	62.969	4.285	48	4.169	4.230	111.44
WAMPC17	FMC	501-01-WBE-003	Battery	445.65	60.399	0.4	50	3.590	60.399	4.290	46	4.245	4.330	114.97
WAMPC18	FMC	501-01-WBE-003	Battery	473.49	64.172	0.4	80	3.630	64.172	4.265	55	4.245	4.300	118.32
WAMPC25	FMC	501-01-WBE-003	Battery	370.441	50.206	0.4	180	3.630	50.206	4.287	52	4.2331	4.233	114.88
WAMPC26	FMC	501-01-WBE-003	Battery	448.30	60.758	1.0	180	3.629	60.758	4.270	55	4.233	4.300	117.07
WAMPC27	FMC	501-01-WBE-003	Battery	467.20	63.320	0.4/1.0/2	130	3.428	63.320	4.248	60	4.9229	4.275	115.24
WAMPC28	FMC	501-01-WBE-003	Battery	466.70	63.252	1.0	170	3.430	63.252	4.306	55	4.300	4.275	114.39
WAMPC29	FMC	501-01-WBE-003	Battery	454.70	61.626	1.0	105.000	3.620	61.626	4.338	80	4.275	4.240	119.16
WAMPC30	FMC	501-01-WBE-003	Battery	453.40	61.449	1.0	95	3.630	61.449	4.238	70	4.220	4.200	116.31
W AMPC32	FMC	501-01-WBE-003	Battery	462.30	63.274	1.0	175	3.560	63.274	4.316	38	4.264	4.277	118.45

Note:

Cathode surface: 632.26 cm<sup>2</sup>

WAMPC11 Shaded due to a burr in the grid edge

WAMPC13 used a solid aluminum current collector

WAMPC15 through WAMPC23 used 10 psi CO<sub>2</sub> head pressure to drive the electrolyte into the cells

WAMPC19 through WAMPC24 shorted during the charge cycle

WAMPC24,25 used a solid aluminum current collector with holes in it in place of aluminum grid. plus 3 layers of 3M-E003 separator plus 1 layer of celgard 2300 par Interface to help prevent shorting. No CO<sub>2</sub>

WAMPC25 (New test fixture)

WAMPC26 Aluminum grid, 1.0mA/cm<sup>2</sup> charge rate, 3 layers 3M-E003 + 1 layer celgard 2300 per interfaceWAMPC27, Aluminum grid, 0.4mA/cm<sup>2</sup> for the first (3/4%) Ah, then 0.2 mA/cm<sup>2</sup> for the remaining (1/4%) Ah

WAMPC28 through WAMPC32 built like WAMPC26

\*0.55 Faradays per mole, i.e., x in Li<sub>x</sub>CoO<sub>2</sub> is 0.45.\*\*active material only (Li<sub>x</sub>CoO<sub>2</sub>) does not include inert components of the mix.

\*\*\*OCV=open circuit voltage, in volts.

## Chapter 5

### Test Results

Following the scheme of Alliant Techsystems' Design/Development Philosophy, testing was broken down into a number of categories. Given below is an outline of the testing of precharged Li/Li<sub>0.5</sub>CoO<sub>2</sub> cells. Following that are representative results of the cells tested in the various categories.

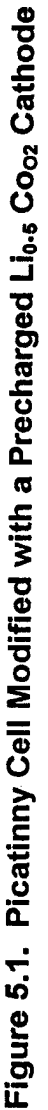
Section Title	TEST ENVIRONMENT
Preprogram Testing	<ul style="list-style-type: none"> <li>Modified Picatinny Cell 9275567 stored at room temperature and at 149°F discharged at room temperature.</li> <li>Flat plate cell cycled at HWAM rates at room temperature tests.</li> </ul>
Fixtured Cell Testing at Environmental States Hermetic Cell Performance Testing at Environmental States	<ul style="list-style-type: none"> <li>Room temperature multi-plate cell tests.</li> <li>Cold temperature multi-plate cell tests.</li> <li>Room temperature performance tests. (WAMH05)</li> <li>Four-month storage at room temperature followed by -25°F discharge performance test. (WAMH07)</li> <li>Three-month storage at 65°F followed by 145°F discharge performance test. (WAMH20)</li> <li>Three cells in series; discharge performance at room temperature.</li> </ul>
Hermetic Cell Safety Testing	<ul style="list-style-type: none"> <li>External short circuit safety test. (WAMH08 and WAMH22)</li> <li>Internal short circuit safety test. (WAMH09)</li> <li>External short-circuit and discharge reversal safety test. (WAMH18)</li> <li>Short electrolyte fill discharge safety test. (WAMH06)</li> </ul>

#### Preprogram Testing

Preprogram testing, done as part of Naval Surface Warfare Center Option 7 to the 100 Ah Program, Contract N60921-93-C-0060, evaluated precharged Li<sub>0.5</sub>CoO<sub>2</sub> cathode material in an Army munitions cell which is a production item, Picatinny Arsenal Cell 9275567 (Alliant Techsystems' ATK G2666), Figure 5-1, modified for that purpose. The modification consisted of replacing the vanadium pentoxide cathode of the G2666 by a Li<sub>0.5</sub>CoO<sub>2</sub> cathode, and, for some

cells, using only the  $\text{AsF}_6$ -salt in lieu of the DSMF electrolyte of the G2666. The lithium metal anode and Veritek Type M separator were the same as for the G2666. The storage and test matrix of 26 of these cells is shown in Figure 5-2. Results of testing to this matrix is shown in Figure 5-3 for a typical fresh cell and in Table 5-1 for all stored cells summarized in hours of run time to 3.33 volts. That voltage corresponds to the cut off voltage per cell for HWAM applications. For three cells connected in series, ten volts is the minimum HWAM voltage.

Preprogram testing of a flat plate cell was done as an early attempt to fabricate flat plate cathodes from dry precharged  $\text{Li}_{0.5}\text{CoO}_2$ /graphite mix material. Characterization of these cells included cycle life testing. The flat plate cells were fabricated with microporous polypropylene (Celgard 2300) separators (See Section 6) and cycled through a test profile that included an initial pulse load of  $5.0 \text{ mA/cm}^2$  to begin each discharge. The pulses were at the same pulse rate anticipated for the HWAM battery (3.75 amp equivalent). Following the pulse, each discharge continued at a rate designed to test the ability of the cathode. The rates were increased for successive cycles, first at  $0.5 \text{ mA/cm}^2$ , second at  $1.0 \text{ mA/cm}^2$ , and third at  $2.0 \text{ mA/cm}^2$ . Then the process was repeated. All of this testing was conducted at room temperature. Figure 5-4 is a plot of one of two cells tested to this regime. As expected, the cycle life was less than for cells built<sup>1</sup> to achieve about 50 cycles because the formulation of the electrolyte for those cells included dissolved carbon dioxide, a component known to improve the cycle life of lithium metal anodes. It may be seen from the results in Table 5-1, that the SSMA performed as well as the DSMA. That result is desirable as it reduces cost.



## Notes:

Placed in Storage: Dec. 12, 1994

Removed from Storage: June 16, 1995

ATK No. G2666

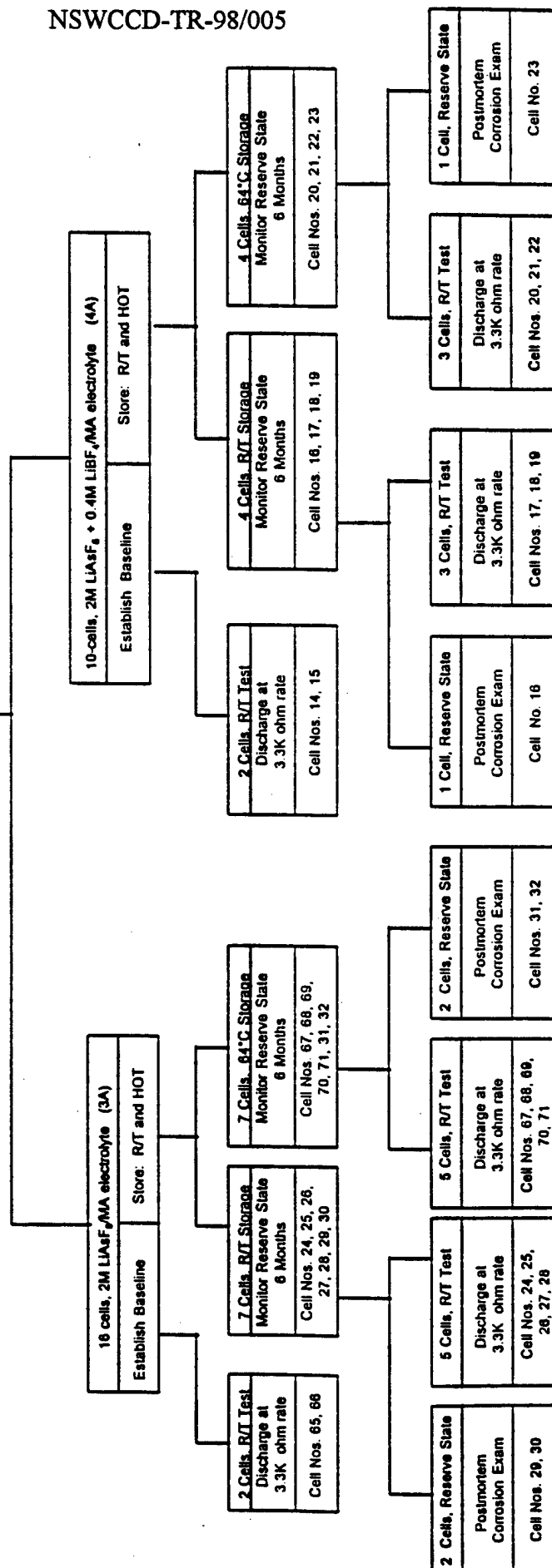
Rated Capacity = .15 amp hour

3.3K ohms = 1 week rate

28-cell build, two electrolytes, precharged $\text{Li}_0.5\text{CoO}_2$ cathode
1 month reserve cell storage at room temperature Examine reserve status

NSWC/ARDEC Precharged  $\text{Li}_0.5\text{CoO}_2$  Reserve Cells  
 Option 7 - Contract No. N60921-93-C-0060  
 Picatinny 927567 Modified Cells, Performance Verification (ATK G2666)  
 Test Matrix

NSWCCD-TR-98/005

Figure 5-2. Storage and Test Matrix for Option 7, Picatinny Cell (Modified with  $\text{Li}_0.5\text{CoO}_2$  Cathodes)

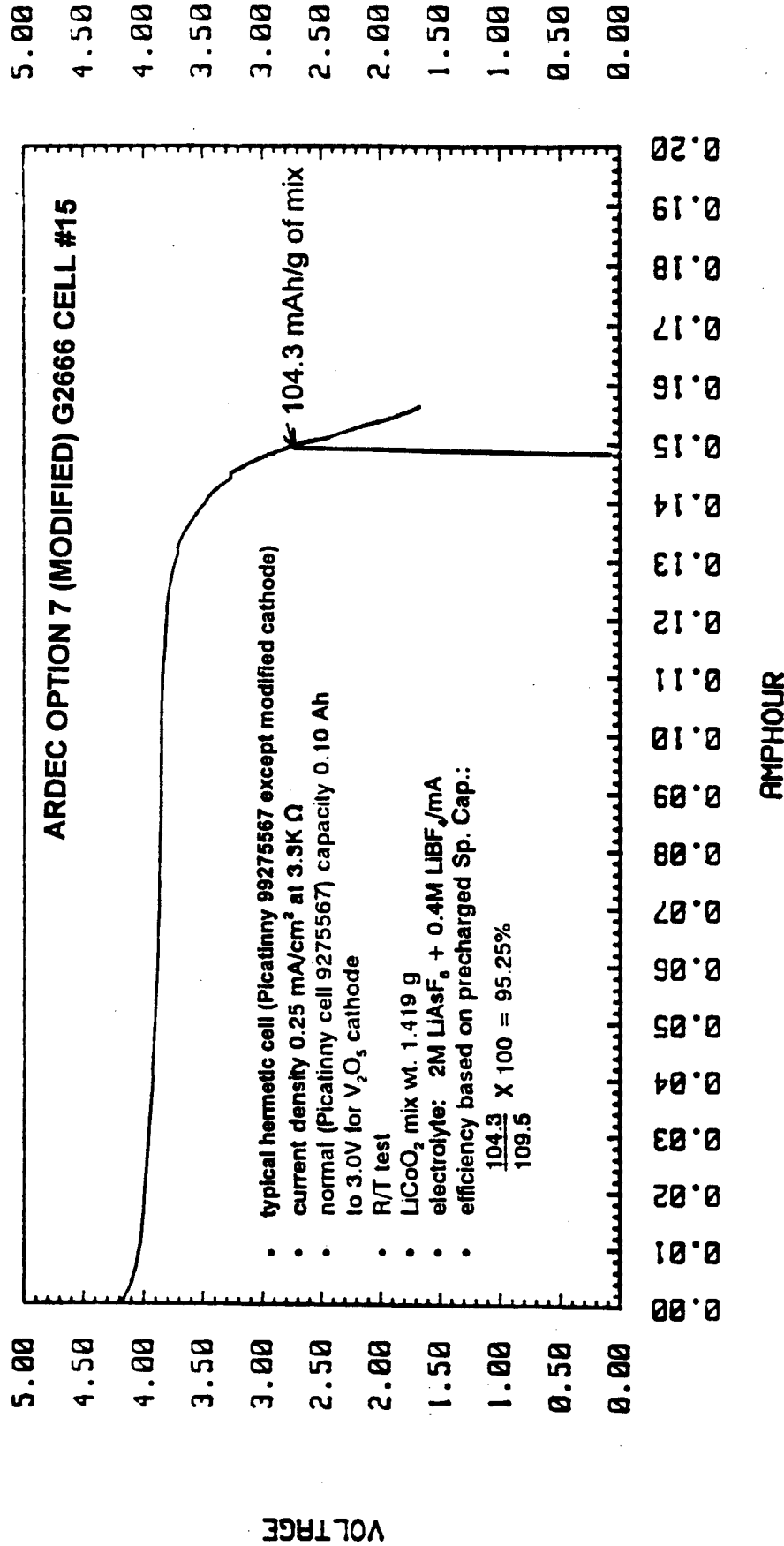
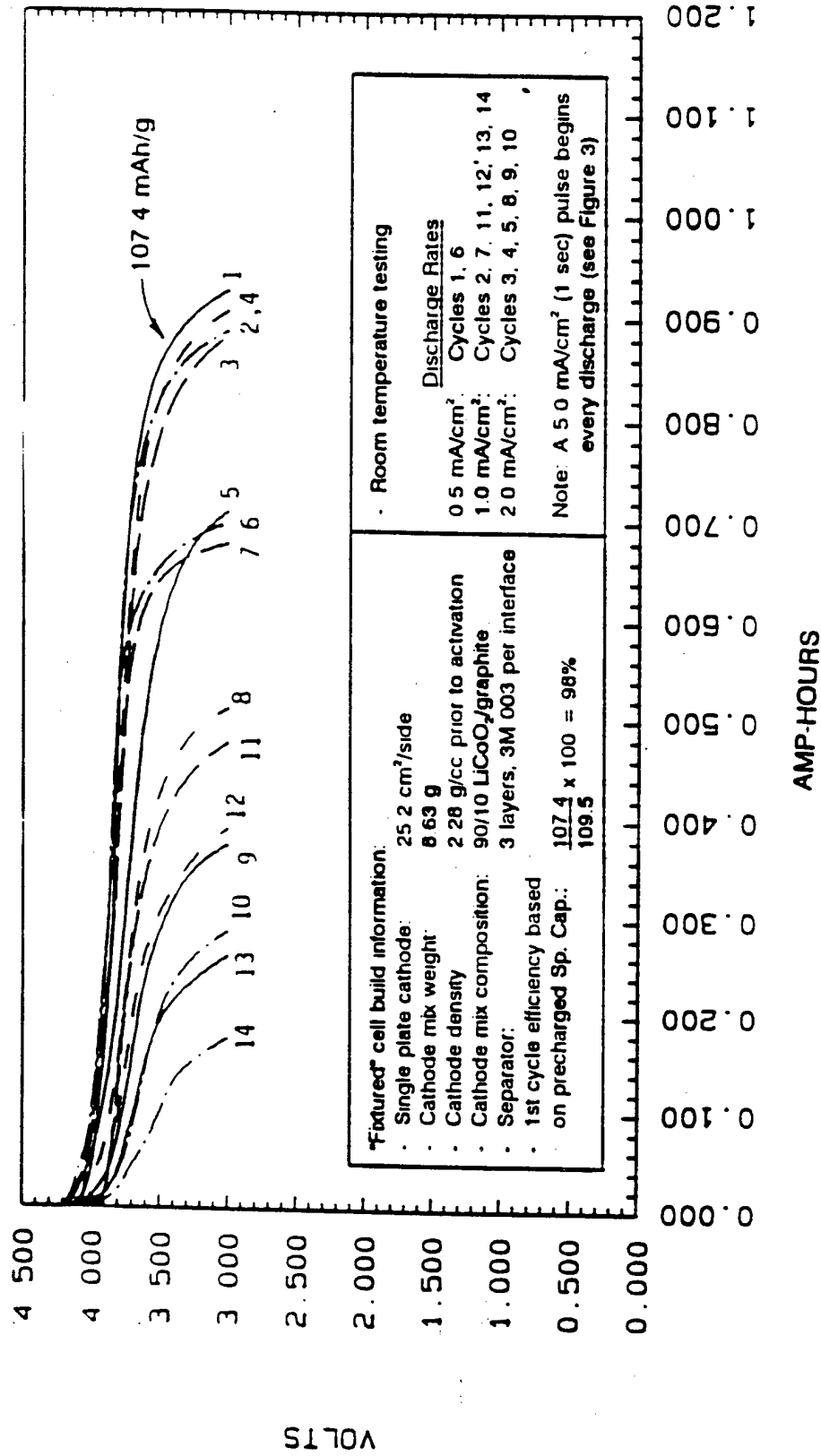


Figure 5-3. Fresh Discharge Performance of Picatinny Reserve Cell in Small Hermetic Hardware (Modified Picatinny Cell 99275567)



**Figure 5-4. Subcell No. 103 of HWAM Type, Reserve Battery Design, Using Precharged LiCoO<sub>2</sub> Cathode and Cycled After First Discharge at the Indicated Rates**



**Table 5-1. Modified Picatinny 9275567 Cells with Precharged Cathodes  $\text{LiCoO}_2$   
Stored in Reserve State - 6 Months  
Discharged with 3.3K Ohm Load**

Cell No.	Channel No.	Stored Condition	Electrolyte	Hours to 3.33 Volts	
17	71	6 months R/T	DSMA	122	Average Run Time: 121.66 hours
18	72		DSMA	122	
19	73		DSMA	121	
24	61	6 months R/T	SSMA	121	Average Run Time: 120.60 hours
25	62		SSMA	120	
26	63		SSMA	119	
27	64		SSMA	121	
28	65		SSMA	122	
Equivalent to 10 Years Reserve Storage					
20	74	6 months, 60°C	DSMA	115	Average Run Time: 114.0 hours
21	75		DSMA	113	
22	76		DSMA	114	
67	66	6 months, 60°C	SSMA	114	Average Run Time: 115.40 hours
68	67		SSMA	115	
69	68		SSMA	116	
70	69		SSMA	117	
71	70		SSMA	115	
Notes:		SSMA: 2M LiAsF <sub>6</sub> / MA DSMA: 2M LiAsF <sub>6</sub> + 0.4M LiBF <sub>4</sub> / MA 3.33 Volt Cutoff			

### Fixtured Cell Testing at Environmental States

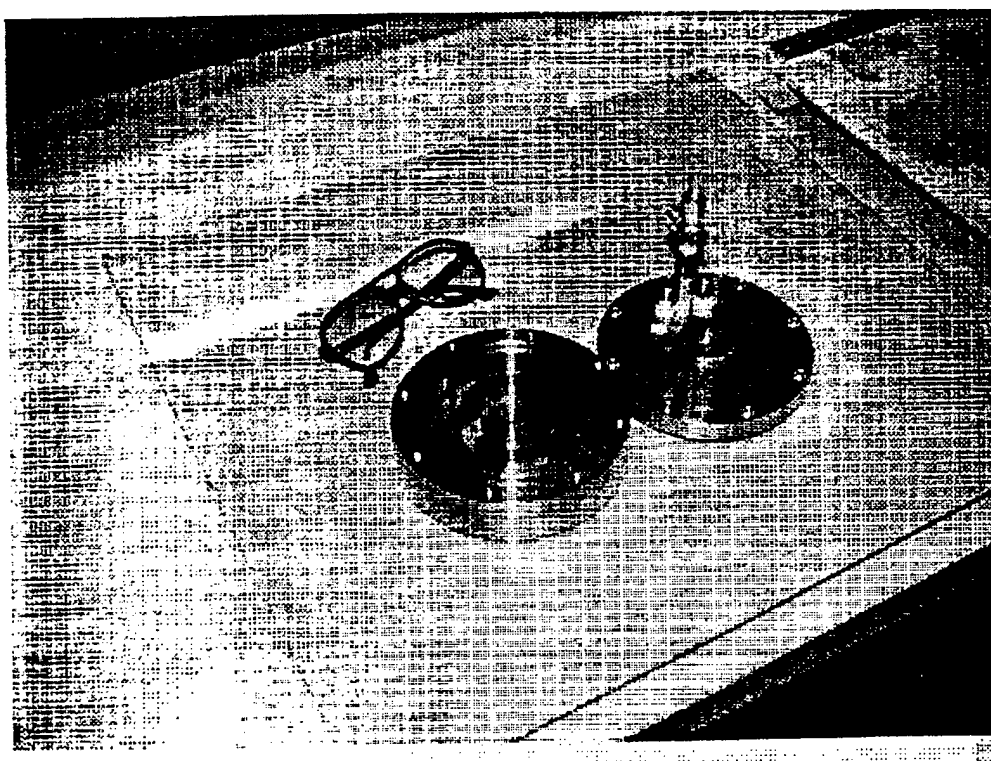
Fixtured cell testing on this program had the purpose of simulating a full HWAM cell (one of three needed to meet the HWAM power requirements), without the long lead preparation needed to create a hermetic cell case. Photographs of a typical HWAM fixtured cell case and cell assembly are shown in Figures 5-5 through 5-8. Drawings of the fixture are included in Appendix A, HWAM Cell Drawing Package.

Fixtured cell testing done at room temperature is summarized in Table 5-2. These tests all had a background load of 400 milliamperes and pulse loads of 3.75 amperes every 5 hours. This regime was used to simplify the complex and lengthy power profile of the actual HWAM (Figure 2-2). It was particularly interesting to note that all of the pulse loads stayed above 2.67 volts. In a three-cell seriesed battery, 2.67 volts per cell provides the 8.0 volt battery voltage that all pulses must exceed. Also, run time, counted to 3.33 volts, exceeded 35 hours. Please refer to Figure 5-9 as a typical example. Voltage history during pulse loads is detailed in Figure 5-10. Each pulse load consisted of four, 3.5 ampere, 0.5 second pulses, with a 2.0 second open circuit between pulses. During this test phase we also checked voltage rise time during activation from a remote reservoir. Since design and build of an actual HWAM reservoir is not a part of this program, only  $T_R$ , or time to raise voltage against cell internal resistance, was measured. This

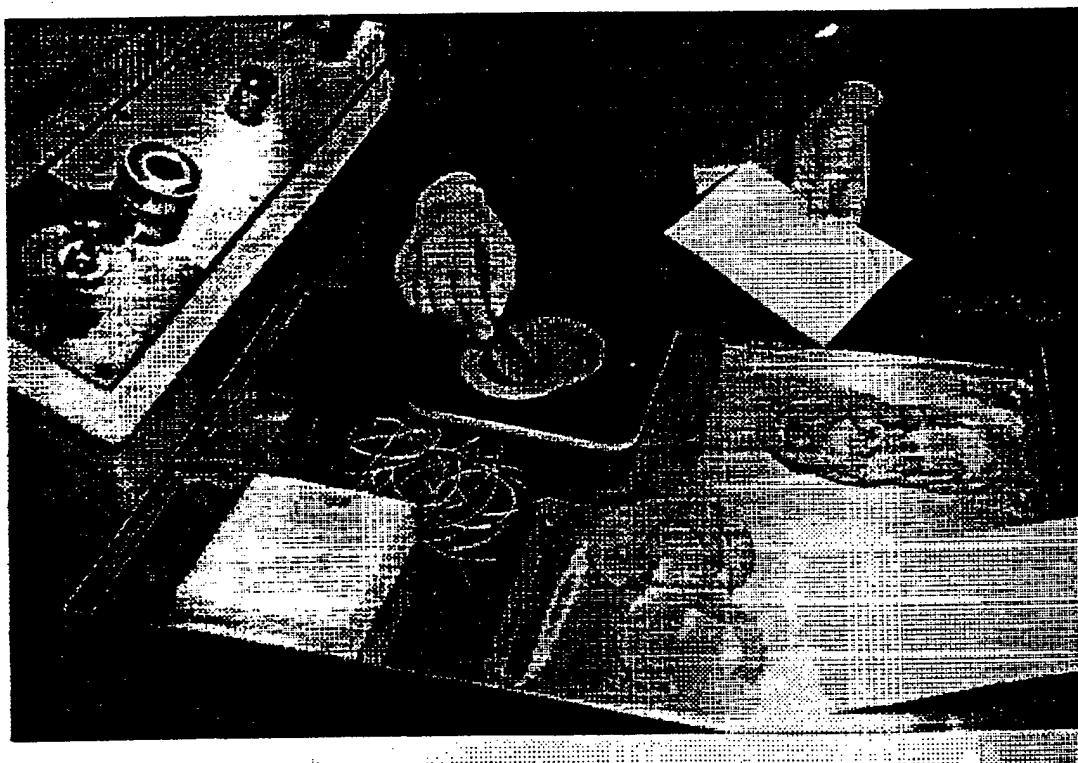
was done without external load applied and is shown in Figure 5-11. Based on the results in the Modified Picatinny Cell 9275567, all cells were built with SSMA electrolyte.

Fixtured cell cold temperature testing proved to be the first performance challenge of the program. Testing at -25°F presented difficulties for the design selections made up until that time. In particular, the 400 milliampere background load caused cells to reach the 3.3 volt cutoff well ahead of required run time. Two design items were varied during this study in an effort to achieve the -25°F load sustaining goal. Cell stack compression and separator type were the variables. Additionally, re-examination of the HWAM power profile showed a 240 milliampere background load to be more realistic to the standby needs than 400 milliampere, which had been primarily specified for the purpose of faster discharge, to hasten test time. Thus a new test profile was programmed, and it is shown in Figure 5-12.

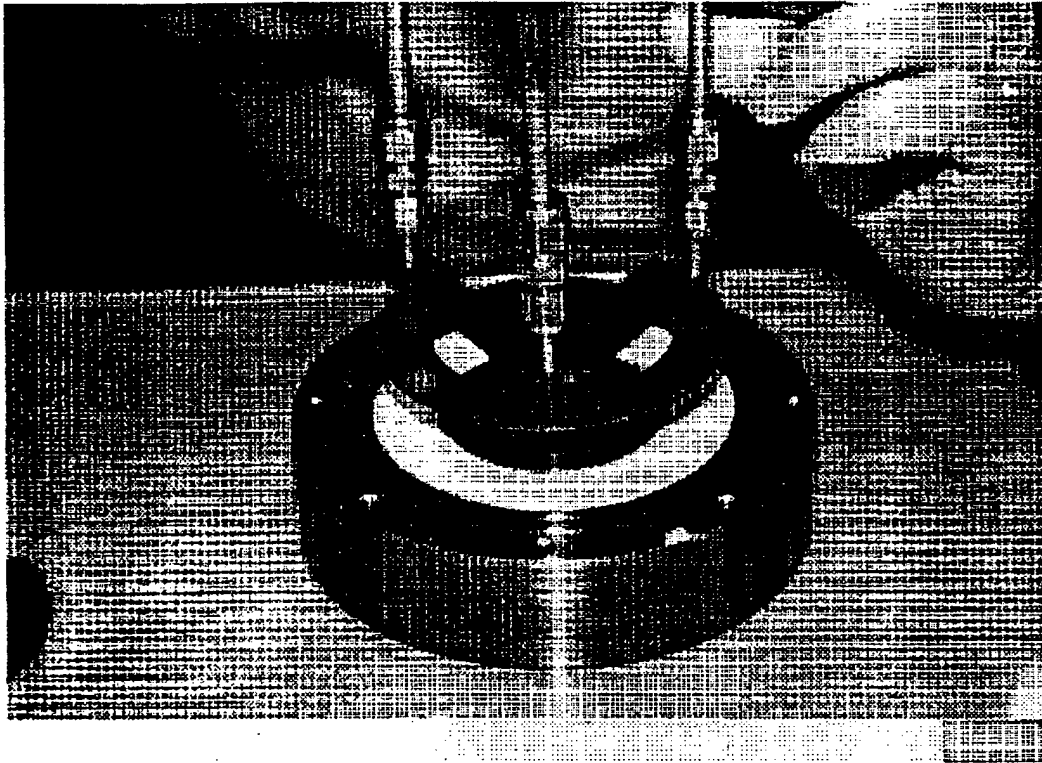
At the conclusion of the fixtured cell testing effort, the combination of elements that held the most promise were an 11-plate cathode cell stack, either Whatman DBSB30A or Veretek TYPE M Separator, and no stack compression. Figure 5-13 showing performance of cell WAMF11 (Whatman separator) and Figure 5-14 for cell WAMF12 (Veretek Separator) shows the ability of the cell design to maintain a 240 milliampere background load and pulse support above 2.67 volts all at the -25°F temperature extreme.



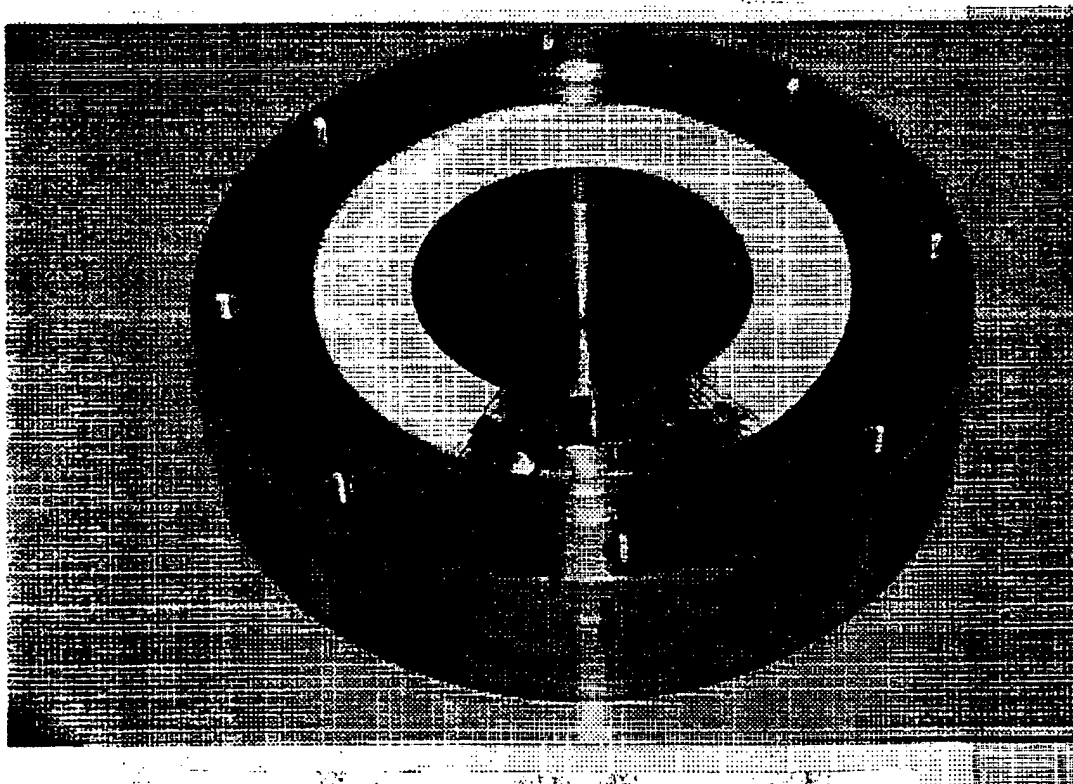
**Figure 5-5. HWAM Single Cell Hardware Test Fixture**



**Figure 5-6. HWAM Anode Assembly - Lithium Foil Press and Trim**



**Figure 5-7. HWAM Cathode Assembly Installation**



**Figure 5-8. HWAM Assembled Cell Stack**  
5-10

Table 5-2. HWAM Fixtured Cell\* Test Data at Room Temperature

Cell Number			WAMF01	WAMF02	WAMF03	WAM05	WAM06	WAMF07
Test Date			10/3/95	10/6/95	10/11/95	10/20/95	11/7/95	11/14/95
Test Temperature			R/T	R/T	R/T	R/T	R/T	R/T
Open Circuit voltage (volts), before test			4.160	4.062	4.160	4.190	4.140	4.110
Activation time (milliseconds)			345		595			280
First sequence of pulses								
	3.50A	Initial	3.070	2.588	3.228	3.291	2.800	2.882
	3.50A	End	2.966	2.350	3.144	3.291	2.840	2.901
	3.50A	Initial	3.144	2.766	3.270	3.313	3.010	3.049
	3.50A	End	2.990	2.322	3.156	3.234	2.880	2.936
	3.50A	Initial	3.196	2.842	3.293	3.327	3.055	3.113
	3.50A	End	3.006	2.316	3.162	3.245	2.905	2.965
	3.50A	Initial	3.230	2.916	3.293	3.342	3.111	3.154
	3.50A	End	3.020	2.308	3.169	3.252	2.919	2.986
Second Pulse (5 hour)								
	400mA	Voltage before pulse	3.822	-	3.790	3.886	3.819	3.844
	3.75A	Initial	3.294	-	3.225	3.371	3.208	3.321
	3.75A	End	3.190	-	3.120	3.33	3.120	3.248
Third Pulse (10 hour)								
	400mA	Voltage before pulse	3.758	-	3.736	3.839	3.790	3.792
	3.75A	Initial	3.226	-	3.222	3.341	3.203	3.288
	3.75A	End	3.116	-	3.118	3.289	3.118	3.200
Fourth Pulse (15 hour)								
	400mA	Voltage before pulse	3.704	-	3.666	3.816	3.760	3.782
	3.75A	Initial	3.174	-	3.120	3.345	3.181	3.278
	3.75A	End	3.044	-	3.008	3.283	3.100	3.212
Fifth Pulse (20 hour)								
	400mA	Voltage before pulse	3.668	-	3.607	3.802	3.726	3.753
	3.75A	Initial	3.100	-	3.100	3.330	3.131	3.254
	3.75A	End	2.916	-	2.916	3.267	3.061	3.183
Sixth Pulse (25 hour)								
	400mA	Voltage before pulse	3.626	-	3.515	3.780	3.683	3.695
	3.75A	Initial	3.086	-	2.911	3.304	3.091	3.194
	3.75A	End	2.998	-	2.772	3.2431	3.000	3.114
Seventh Pulse (30 hour)								
	400mA	Voltage before pulse	3.594	-	3.421	3.741	3.365	3.570
	3.75A	Initial	3.064	-	2.795	3.266	3.000	3.063
	3.75A	End	2.976	-	2.648	3.212	2.950	2.988
Cell Capacity (Ah)			18.81	15.93	15.19	15.43	14.96	15.67
Delivered Capacity (Ah) to 3.33 volts			13.32	-	13.6	***	14.24	13.39
Total run time (hours) to 3.33 volts			33.30	-	34.00	***	35.59	33.33
Cell capacitance (nf)			12.83	13.16	14.15	15.7	16.2	24.5
Precharged LiCoO <sub>2</sub> capacity (mAh/gram)			121.49	118.78	111.51	117.43	114.14	115.41
Note:								
WAMF01: Zero % Compression Vacuum dried cathodes (no heat), 10 cathodes @ 60 mil. thick, uncoated cell fixture								
WAMF02: Zero % Compression, Baked cathodes at 170 deg. C under vacuum, 10 cathodes @ 60 mil. thick, uncoated cell fixture								
WAMF03: 4 % Compression, Vacuum dried cathodes (no heat), 10 cathodes @ 60 mil. thick								
WAMF04: 10 % Compression, shorted when applying compression, cell was not tested, 10 cathodes @ 60 mil. thick								
WAMF05: 4.6 % compression, vacuum dried cathodes (no heat), 11 cathodes @ 54 mil. Thick, 2m LiAsF <sub>6</sub> /MA								
*** the cell was removed from test at 32.53 hours @ 3.72 volts to evaluate the lithium reserve								
WAMF06 4.6% compression, Vacuum dried cathodes (no heat), 11 cathodes @ 54 mil.thick. 2m LiAsF <sub>6</sub> /MA								
WAMF07: 3.0% compression, Vacuum dried cathodes (no heat). 13 cathodes @ 46 mil. thick, 2 layers of separator per interface								
* Electrolyte for all cells was 2M LiAsF <sub>6</sub> in methyl acetate								

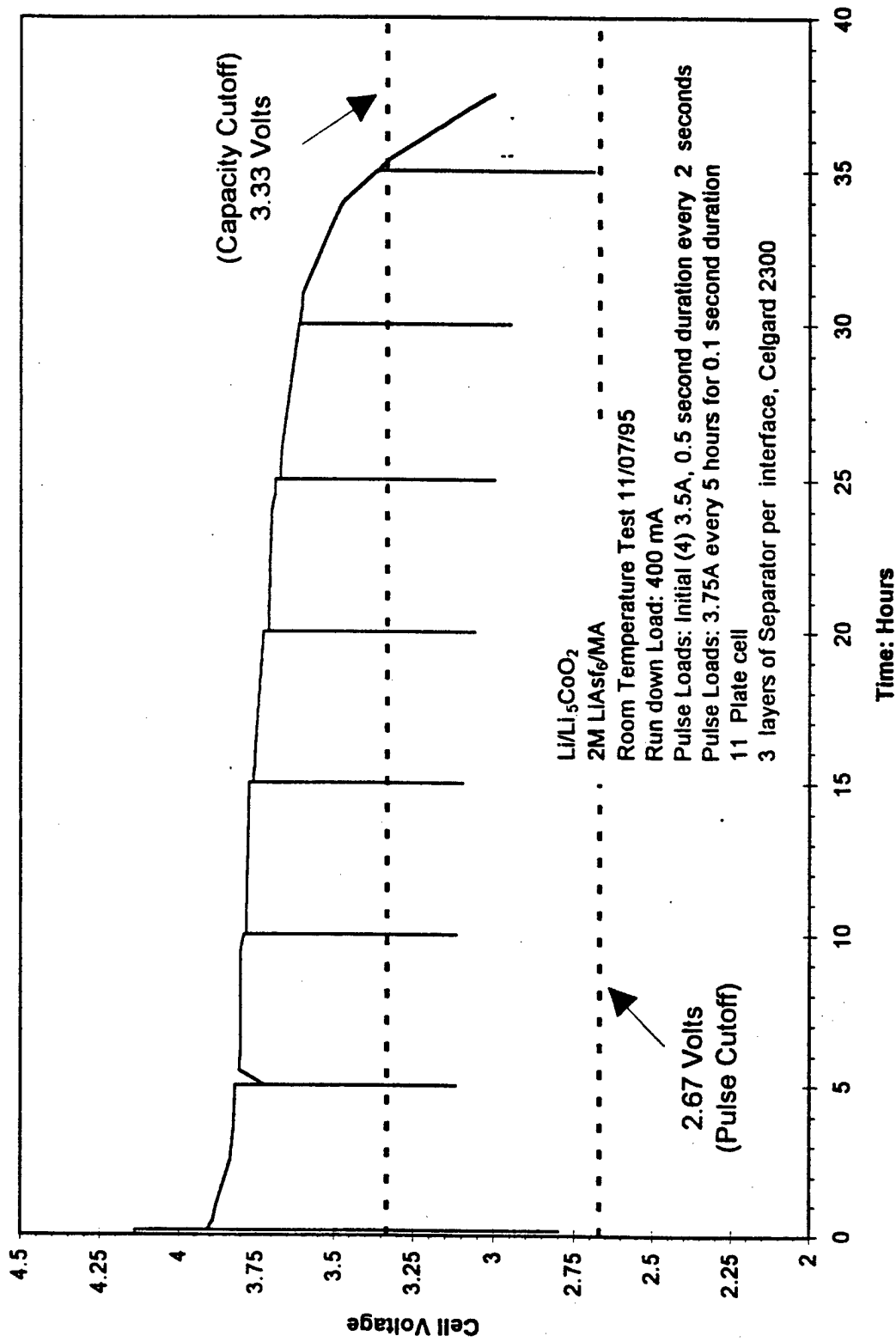


Figure 5-9. Pulse and Capacity Run Down Profile, Cell WAMF06

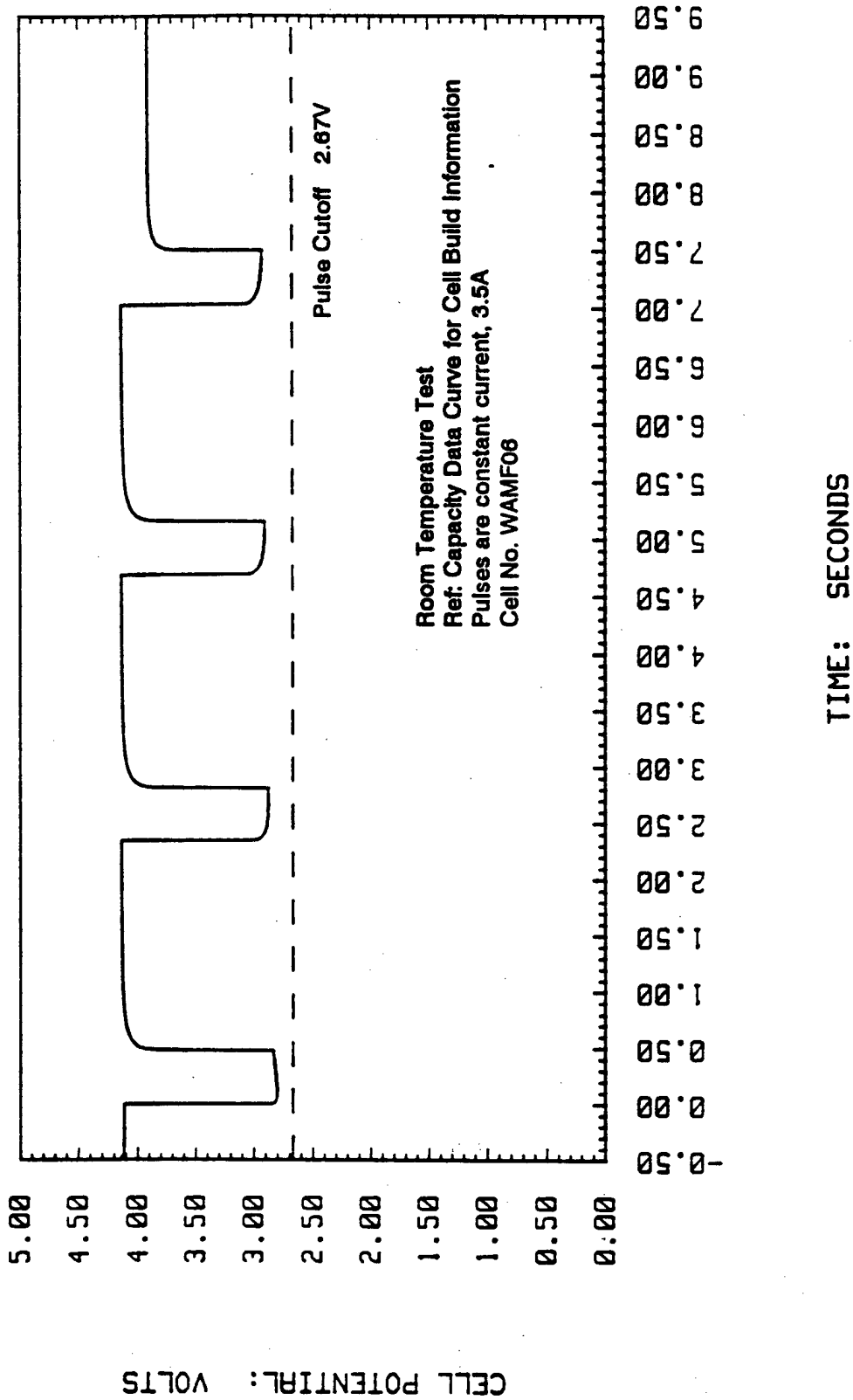


Figure 5-10. Pulse Profile of (4) 3.5 Amp, 0.5 Second Duration at Beginning of Life

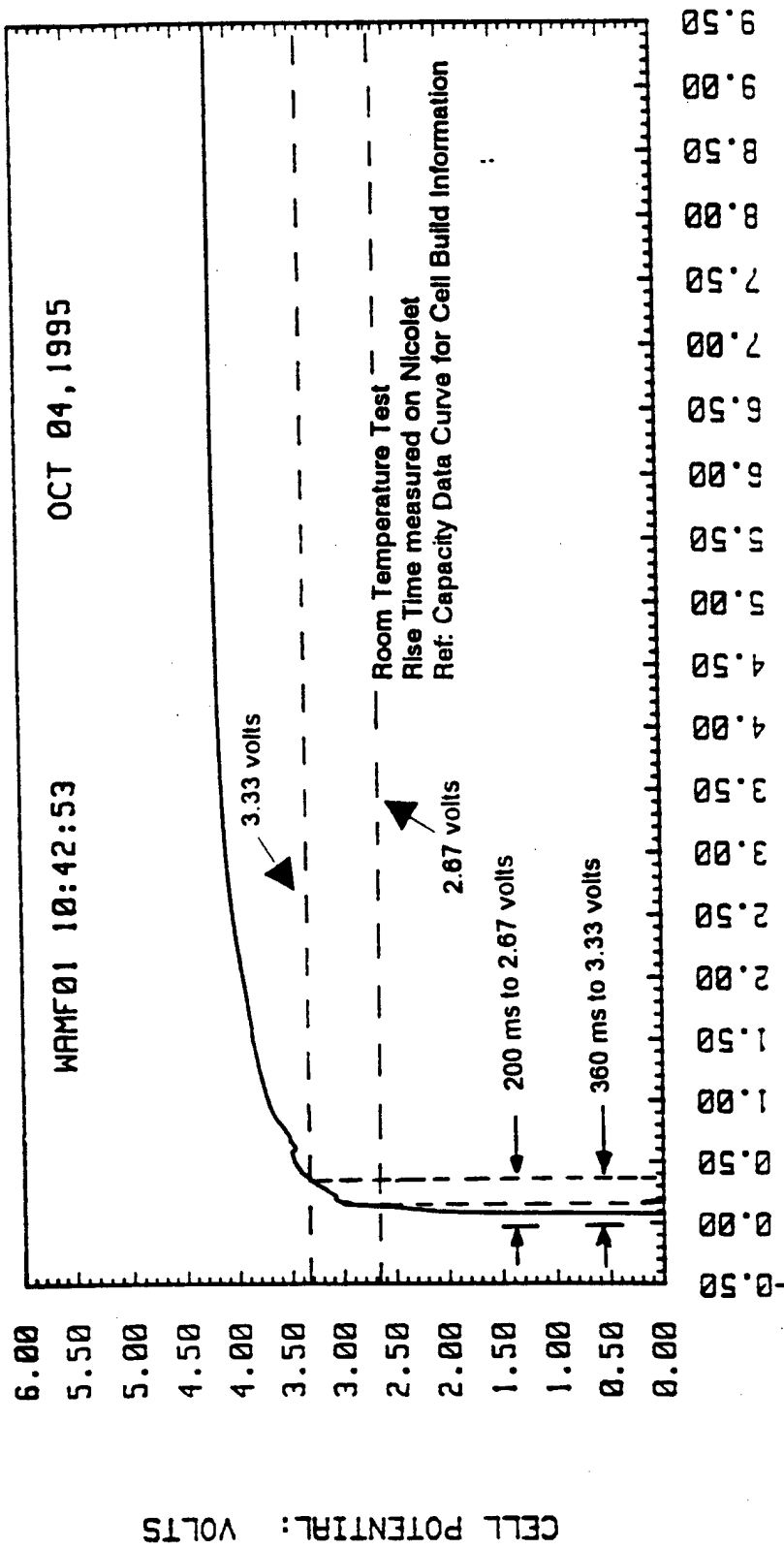


Figure 5-11. No Load Voltage Rise Time ( $T_R$ )



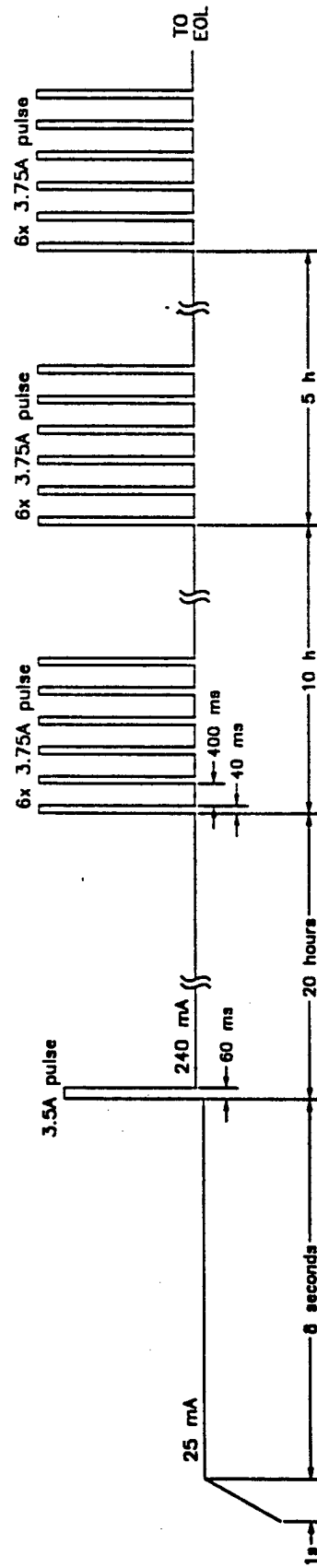


Figure 5-12. Fixtured Cell Test Profile

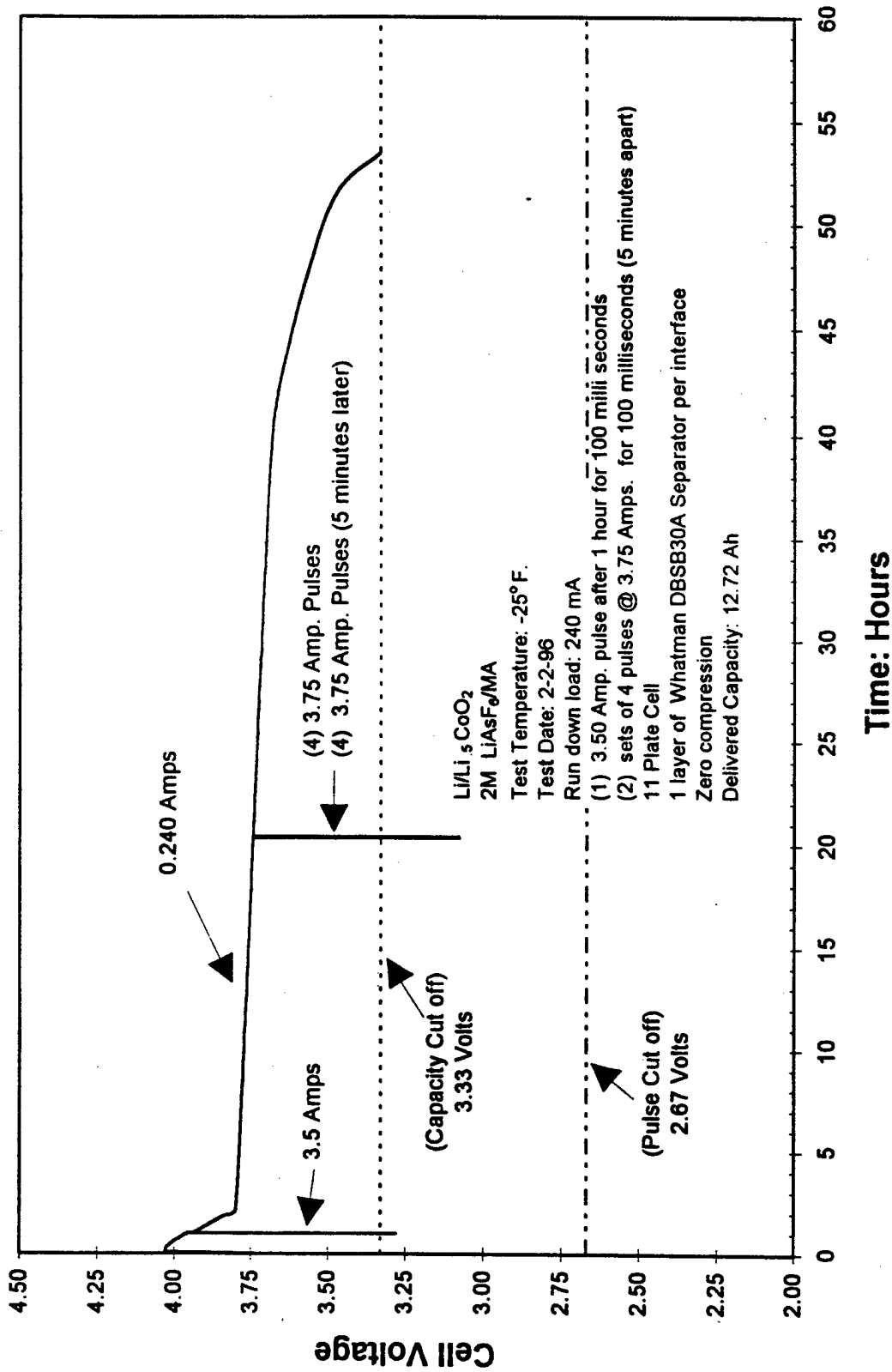


Figure 5-13. Pulse and Capacity Discharge Profile, Cell WAMF11

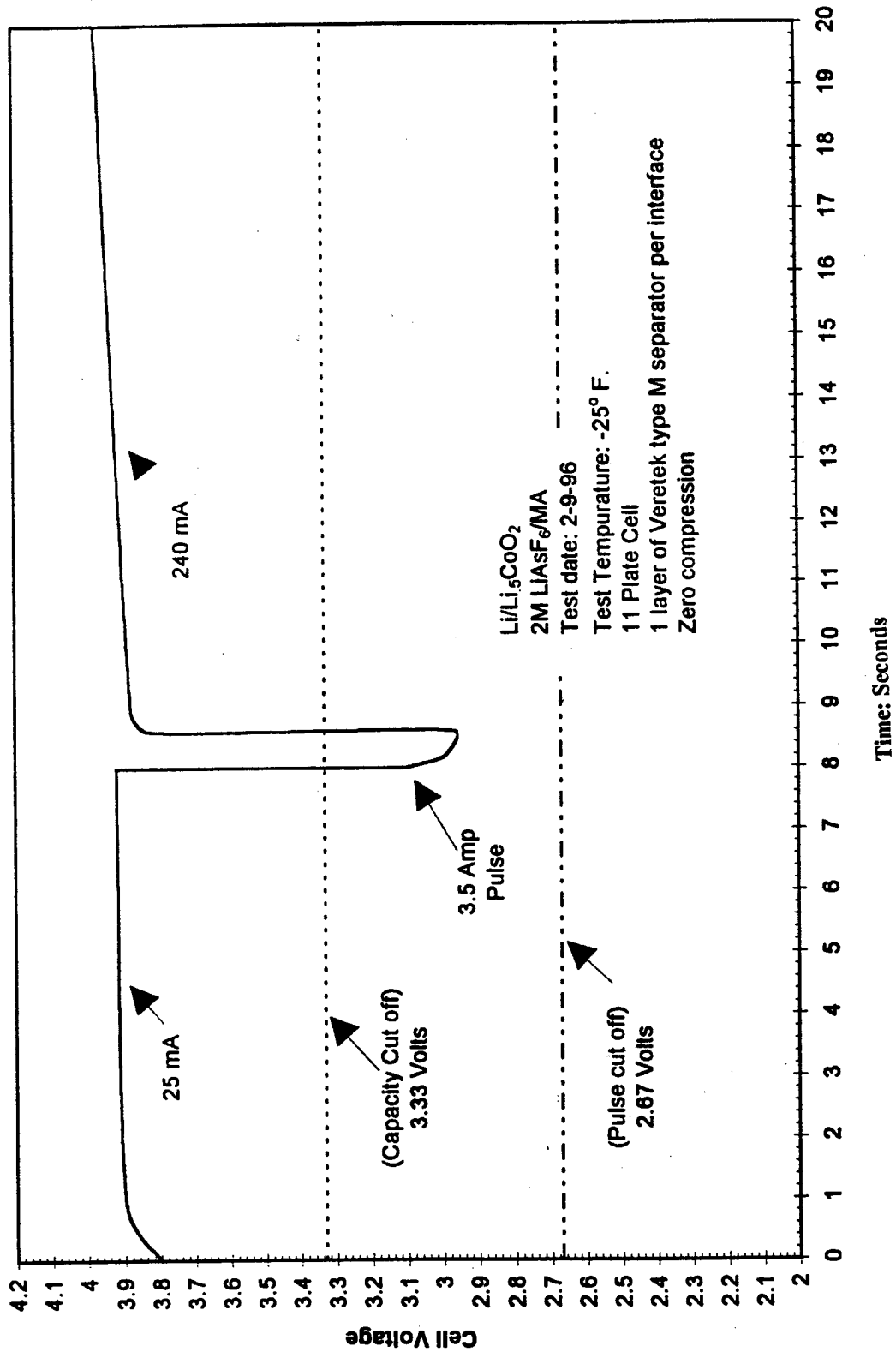


Figure 5-14. Erect Pulse, 8 Seconds After Activation (WAMF12)

## Hermetic Cell Performance Testing at Environmental States

Hermetic cell testing essentially moved the same electrode stack designed during the fixtured cell work into a fully-configured metal cell case. The hermetic cell case and cover were designed to facilitate electrode stack assembly. Sealing the cover onto the cell case required a laser welder to follow a computer-defined path conforming to the cells "C"-shaped geometry. Once sealed, the cells were able to be flooded with electrolyte by means of the fill tube in the terminal end of the cell. Reference to Figure 5-15 for a graphic illustration of the "C"-shaped cell. It was necessary during testing to place the hermetic cells into a test fixture that simulated the battery housing and its external support. The housing is shown in Figure 5-16, in cutaway, as part of the complete HWAM concept battery. Since development of the battery reservoir was not a part of this program, a remote steel sample cylinder was used to hold the cell's electrolyte prior to pressure activation.

Performance testing first concentrated on run time evaluation and capacity achieved at a given temperature. Room temperature performance was verified and was found to equal that obtained in the fixture cell testing. More than 57 hours of run time (13.865 Ah) were obtained from cell WAMH05. Please refer to Figure 5-17 for pertinent data on this test. None of the 3.75-ampere pulses went below the minimum limit of 2.67 volts. Performance was ended when the continued background current of 240 amperes caused the voltage to descend to 3.3 volts. In a 3-cell HWAM battery concept 3.3 volts is equivalent to the 10-volt minimum operating voltage.

A pivotal point was reached in performance testing when cold temperature test results proved to be poorer than expected. These are presented in Appendix B. Design changes made during the fixture cell testing were not enough and an additional change had to be made. Much of the testing had already been conducted with the two molar single salt, methyl acetate electrolyte (SSMA). The more expensive, but better at cold temperatures, double salt methyl formate electrolyte (DSMF) had to be substituted. This was demonstrated in a cell stored for three months at 160°F and in a cell stored for three months at room temperature (See data for WAMH 23 and 24 in Appendix B).

Note that Alliant Techsystems' recommendation is that the DSMF electrolyte is necessary for cold temperature operation and is thus the preferred electrolyte for the HWAM battery. In reviewing the test data of this report, remember that many earlier tests are for cells with the SSMA electrolyte. It is Alliant Techsystems' position that the methyl formate electrolyte does not represent a significant change when conducting safety tests and, as such, the safety test results reported for the methyl acetate electrolyte could be accepted as comparable to those expected for the methyl formate electrolyte.

High temperature performance at 145°F was checked on a cell that had been stored for three months at the specification minimum temperature of -65°F. The test temperature and maximum operating temperature is 145°F. Cell number WAMH20, (Figure 5-18), produced a better than expected 60 hours of run time, 14.365 Ah capacity. Pulse handling capability was, as before, not the life limiting issue. Cutoff at the minimum required voltage, 3.33 volts, was due to

background load; but only after required the run time was exceeded. Similar results were obtained for cell WAMH 21, similarly stored, but discharged at room temperature.

(See Appendix B)

Capacity testing on three hermetic cells connected in series used cells numbered WAMH01, WAMH03, and WAMH04. These three cells functioned as a single HWAM battery and provided voltage above 10 volts for more than 56 hours. The capacity of the battery was 13.65-ampere hours. Figure 5-19 shows the discharge. The reason for the pulsed voltage delay for the first pulse of 3.5 amperes is not known. Electrolyte delivery was via a single reservoir and should have been completed over the one hour of open circuit duration prior to loading the battery with the 3.5-ampere pulse.

Cold temperature testing at -25°F was conducted on cell number WAMH07 after the change was made to the double salt, methyl formate electrolyte. This cell delivered the best overall capacity of any cell, 14.8-ampere hours. Figure 5-20 shows that it also performed well on pulse handling except for the initial pulse of 3.5 amperes. Some exposure of the lithium anode during the fabrication phase of the cell, when dry room conditions were less than ideal due to a power failure, is suspected to have produced a passive layer on its surface. However, that assumption has not been substantiated.

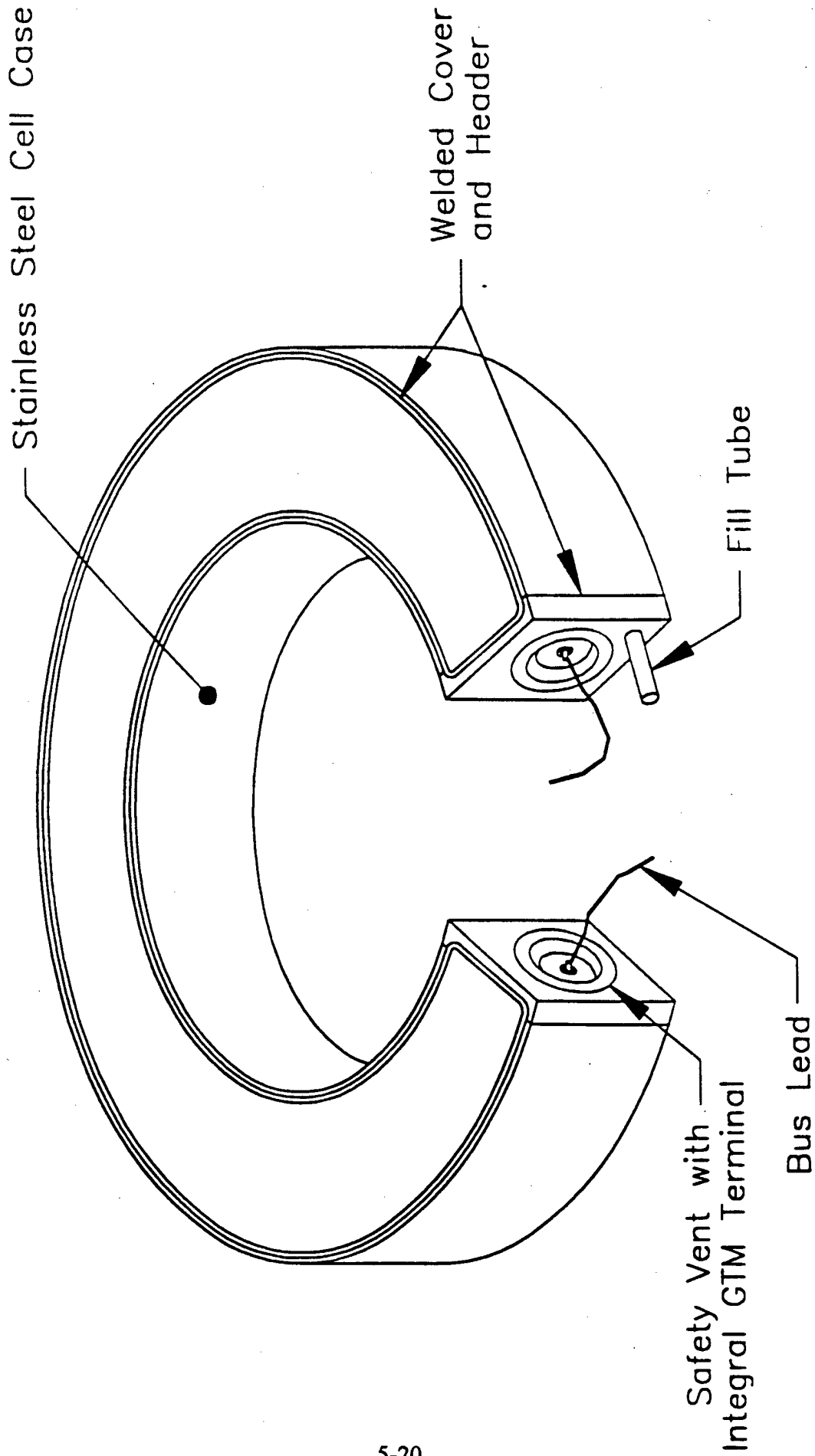


Figure 5-15. Individual Cell Case

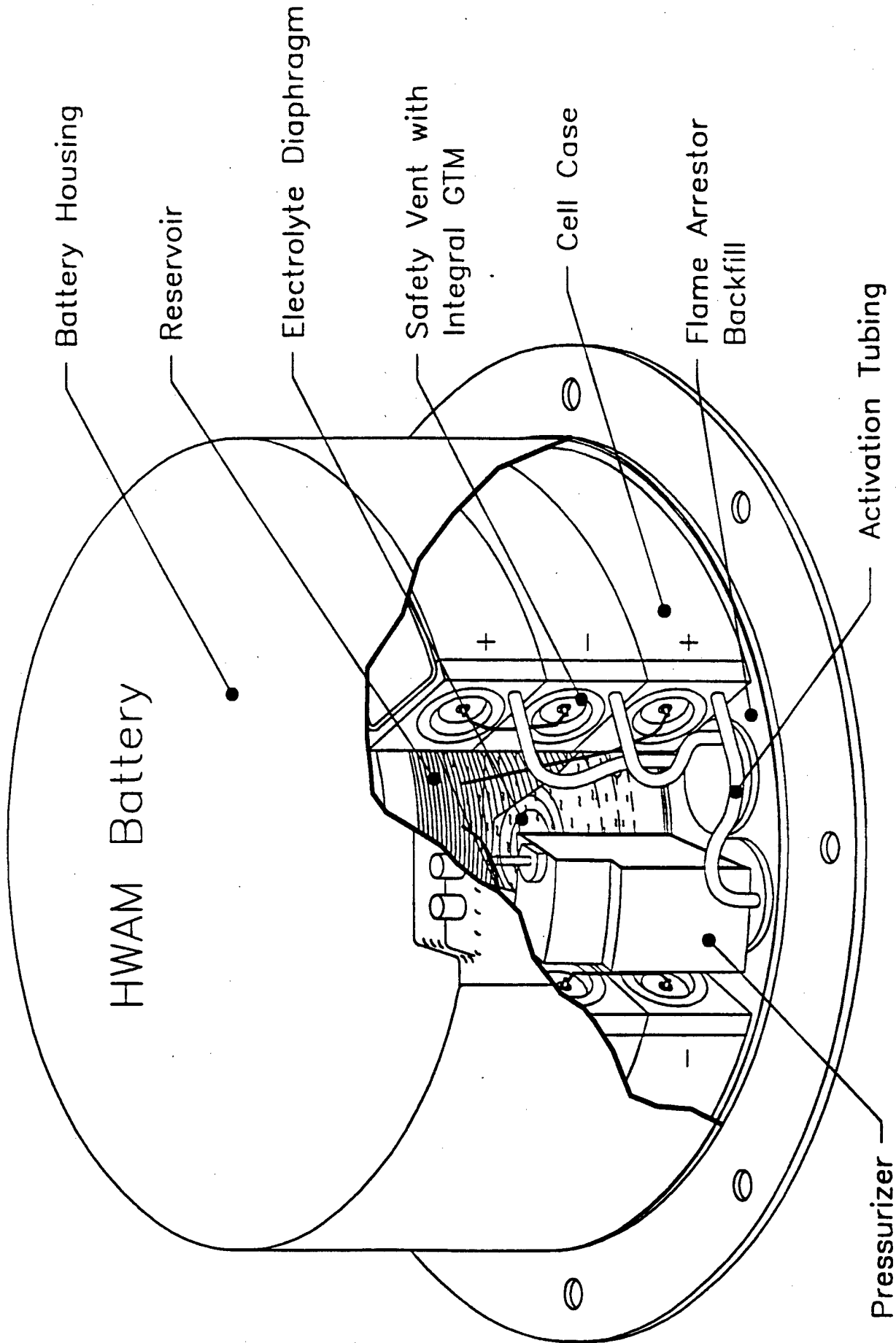


Figure 5-16. HWAM Battery

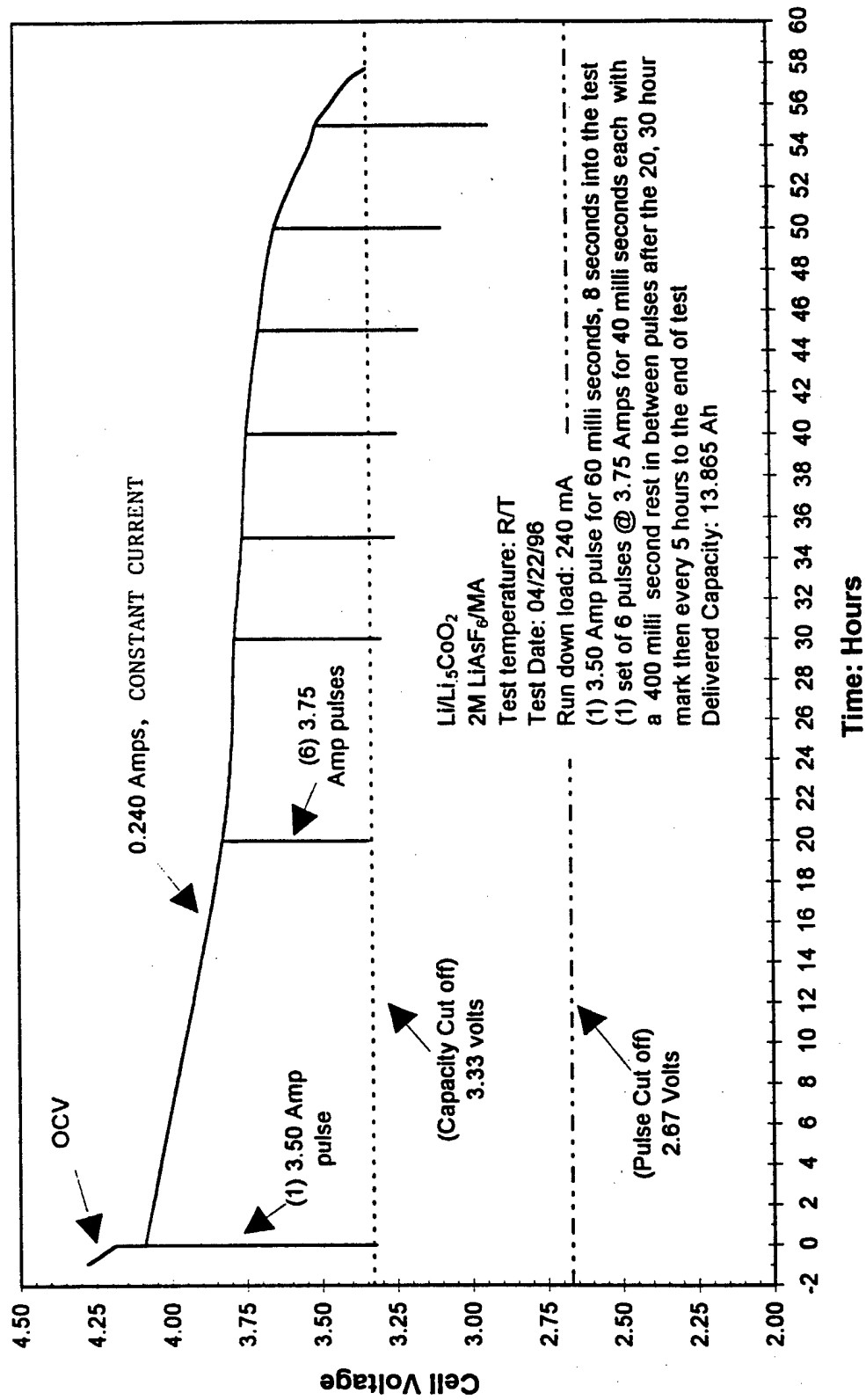


Figure 5-17. Pulse and Capacity Discharge Profile, Cell WAMH05



# 3 Month Storage Cell @ -65°F

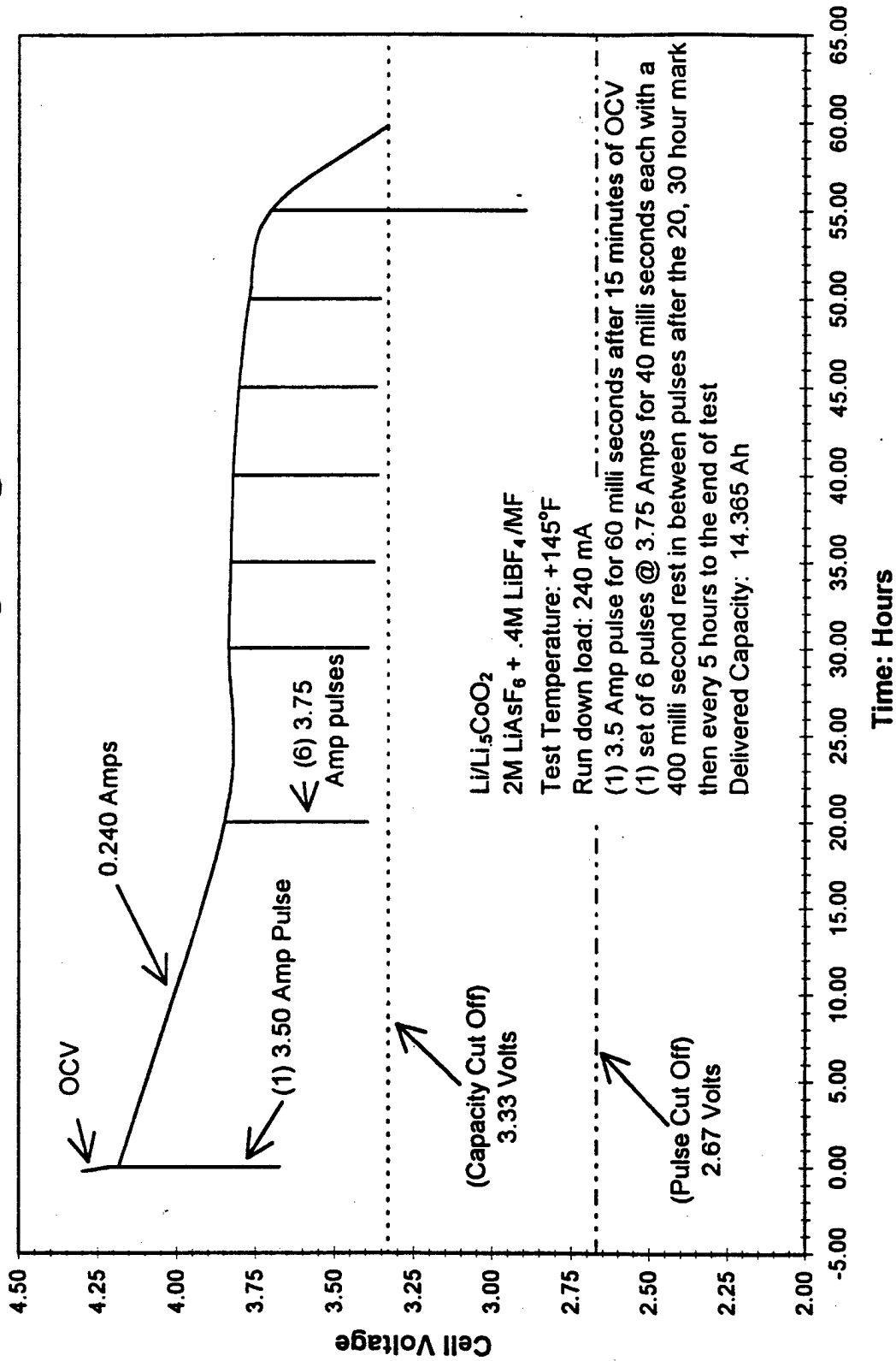


Figure 5-18. Pulse and Capacity Discharge Profile, Cell WAMH20

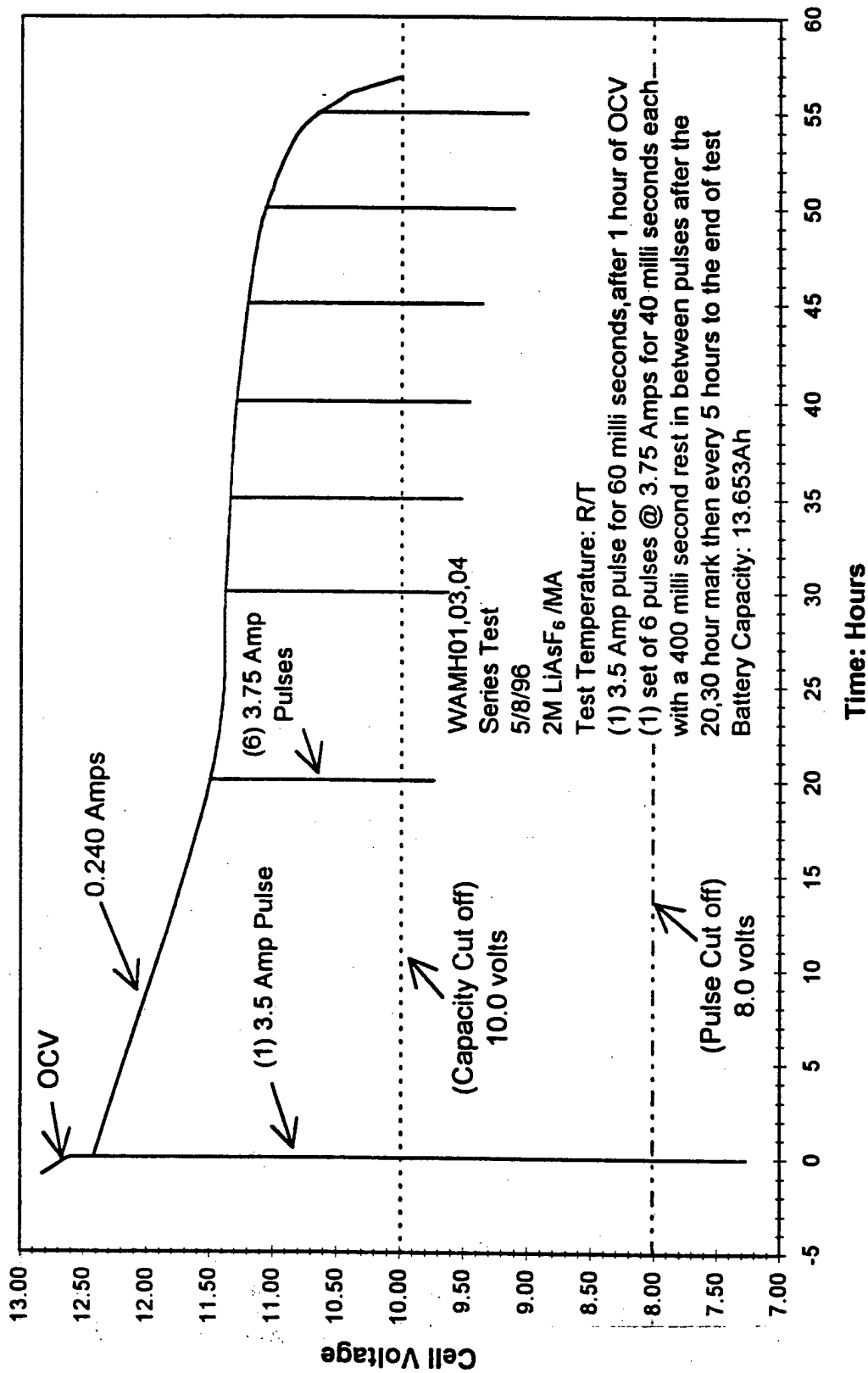


Figure 5-19. Pulse and Capacity Discharge Profile, Series Test

## 4 Month Storage @ R/T

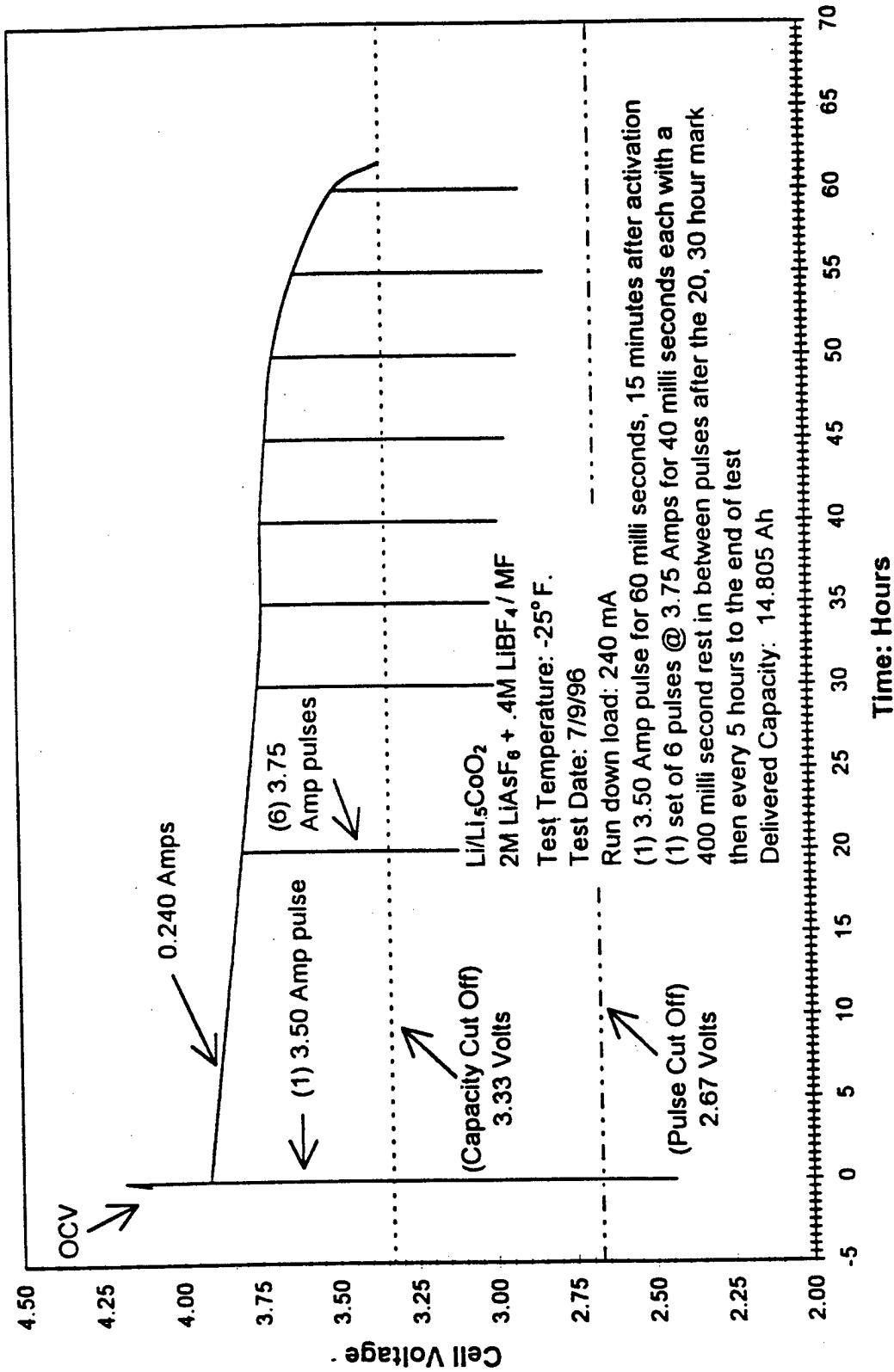


Figure 5-20. Pulse and Capacity Discharge profile, Cell WAMH07

## Hermetic Cell Safety Testing

First in the series of safety tests was an external short circuit test of cell number WAMH08. This cell was activated and allowed to develop full open circuit voltage before the external short was applied by way of a relay. The short was conducted at room temperature (approximately 72°F). The maximum short circuit current developed was 41-amperes. The short circuit was maintained for 30 minutes during which time the temperature increased to 92°F then gradually declined. Figures 5-21(a) and 5-21(b) show the short circuit record and the discharge capacity that followed while under a load of 12 ohms. At no time did the cell rupture or vent. The safety vent diaphragms in the cell terminal header remained intact throughout the entire test. A total of 7.2 ampere-hours were removed during the 12 ohm discharge. The test was repeated with similar results using cell WAMH19 (See Appendix C).

The next short circuit test was also applied externally, but to a cell that had been stored for three months in the reserve-state. This cell, number WAMH22, was activated with the substituted electrolyte; the double salt methyl formate. During the course of the applied short circuit, a maximum current of 30 amperes and a maximum temperature of 116°F were developed. The run time of useful cell capacity, removed after the short circuit provided 30 hours across a 12 ohm load. This load was equivalent to about 0.3 amperes, slightly more than the normal HWAM background load of .24 amperes. (See Figure 5-22(a) and 5-22(b)) The cell did not vent. It remained hermetic throughout the test and subsequent discharge.

To further investigate the effects of cell short circuit behavior, a short circuit test was arranged in which the short was internal to the cell. This was done by fabricating a cell stack (cell number WAMH09) without key separators between electrodes. Specifically, two separators were left out of the middle of the stack and two separators were left out of the top of the stack. In these locations, anode and cathode plates were in direct contact. This fabrication represented the case of misassembly or assembler error. Cell activation occurred at room temperature and the maximum temperature developed during 30 minutes of short circuit was 85°F. After removing the short circuit, a 12 ohm resistive load was applied to rundown the cell. A total of 4.9 ampere-hours were removed during that load application. No venting or rupture occurred during the short circuit. Figure 5-23 provides a profile of the test. Following the internal short circuit test, another external short circuit test was conducted, followed by discharge into reversal with the 12 ohm resistive load. Cell number WAMH18 was the subject cell. No venting or case rupture occurred. The maximum temperature developed during the short circuit was 147°F with a maximum short circuit current of 22 amperes (Figures 5-24(a-c)).

Finally, an abuse test was conducted to simulate the scenario of an underfilled cell stack. This would happen if the reservoir collapsing force misfired or partially closed the reservoir. In an unlikely case where only 10% of the electrolyte in the reservoir is delivered to the cell stack a severe electrolyte starved condition would exist. Cell WAMH06 was tested under these conditions while being loaded with the full background load of 240 mA. Initially, after 2 hours of open circuit, a 3.5-ampere pulse was applied prior to the background load. No venting or case rupture occurred and 1.38 ampere-hours of capacity were removed (Figure 5-25).

page 1 of 2

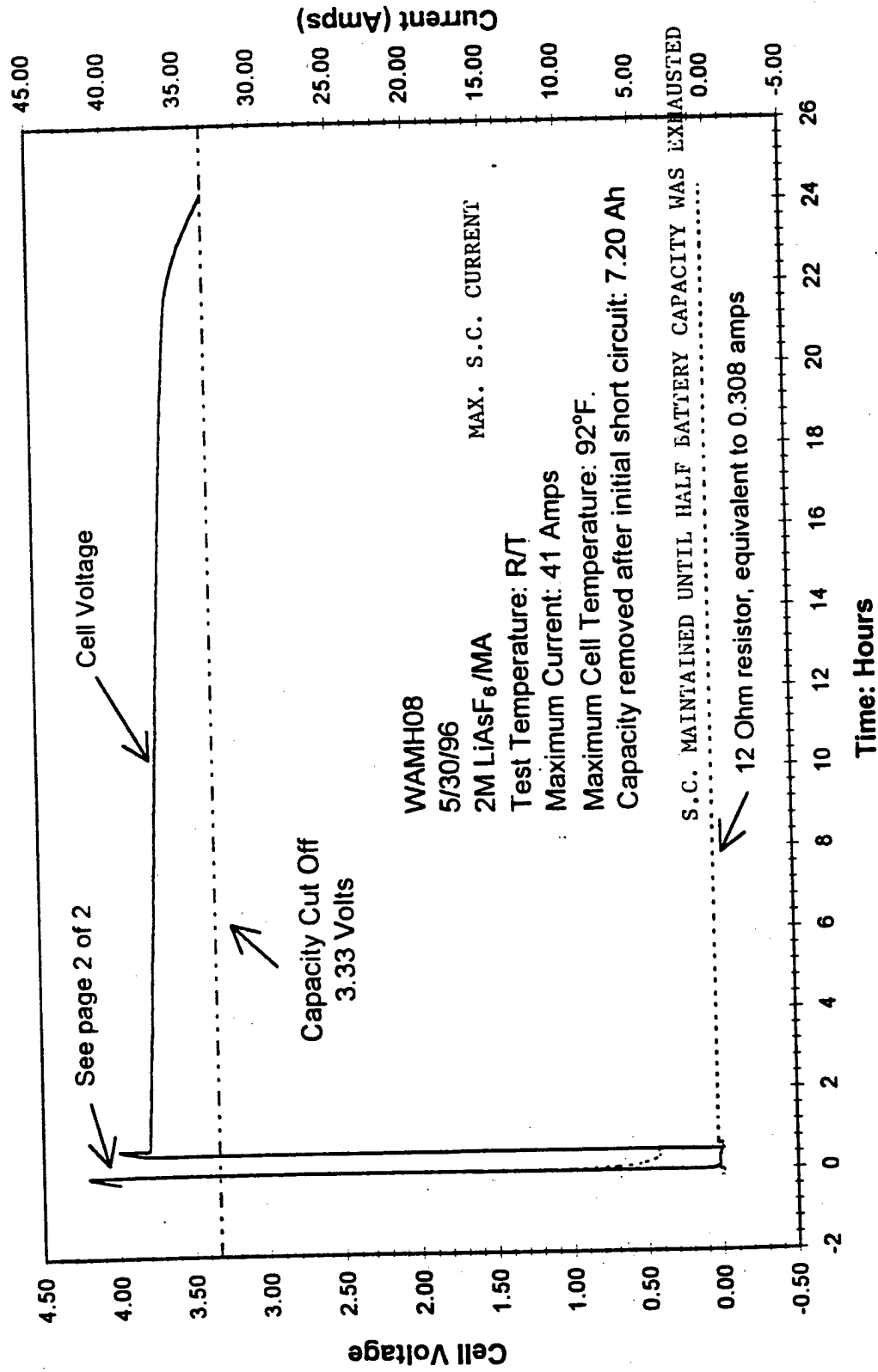


Figure 5-21(a). External Short Circuit Test, WAMH08

Page 2 of 2

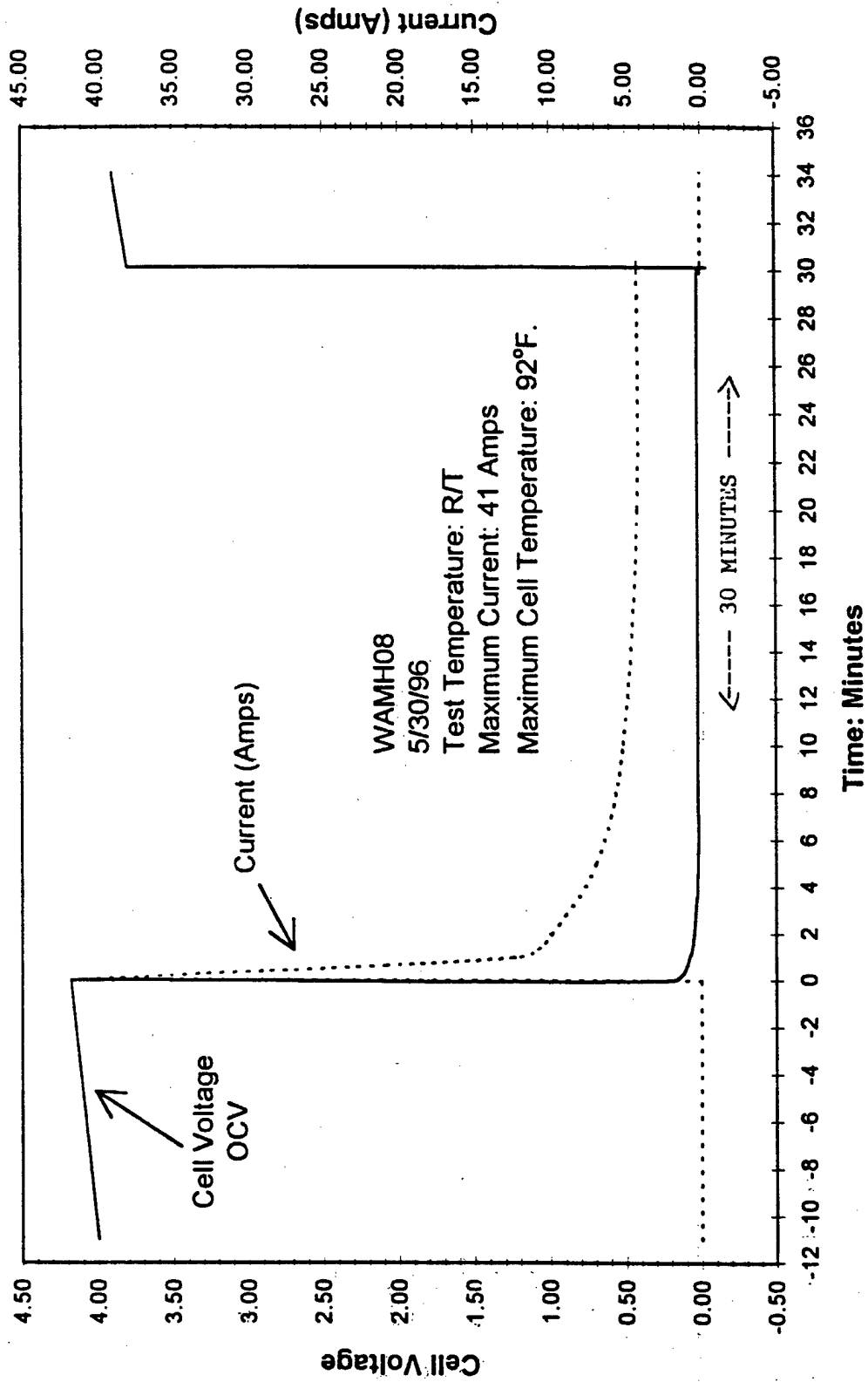


Figure 5-21(b). External Short Circuit Test, WAMH08

## 3 Month Storage @ R/T, (page 1 of 2)

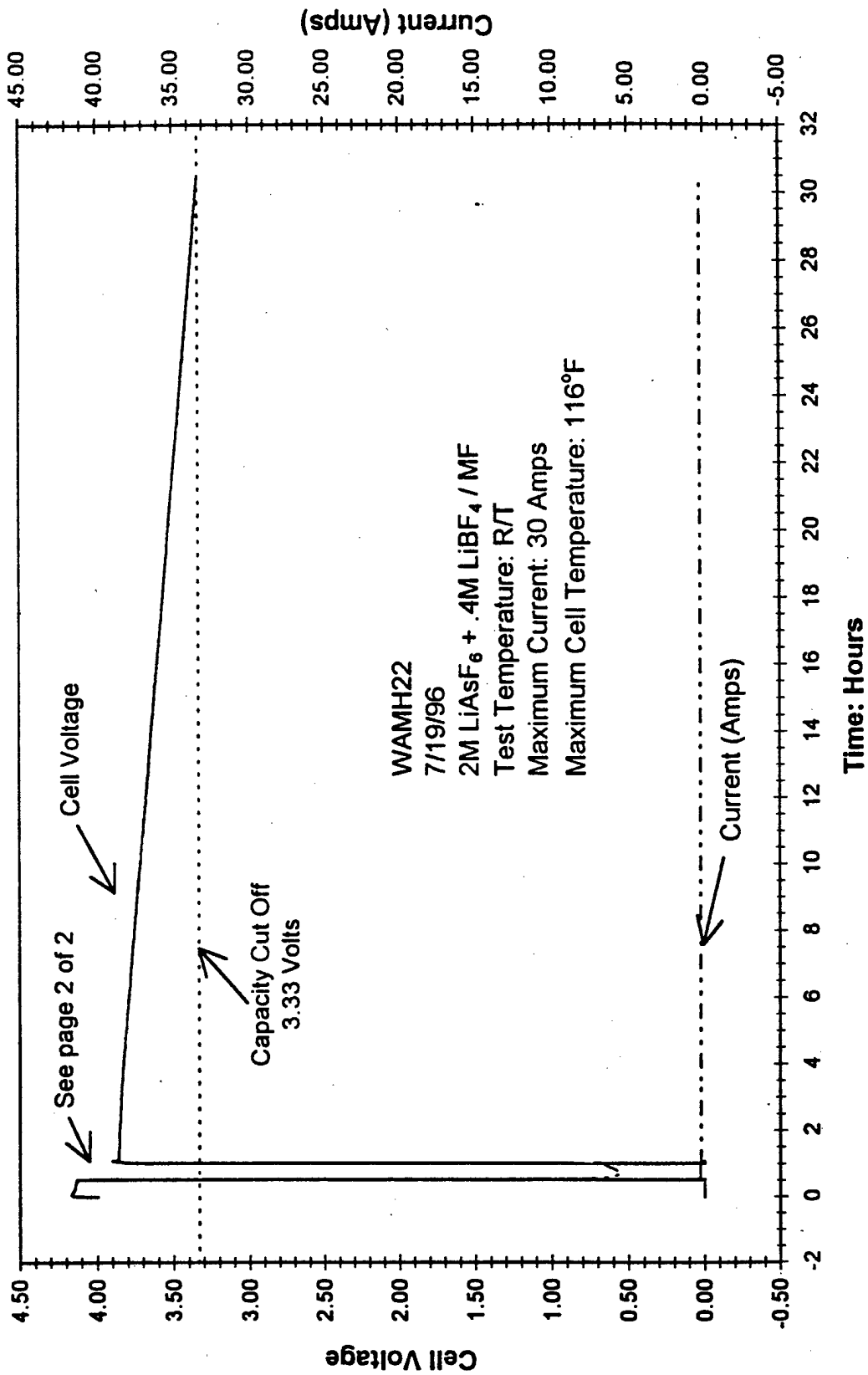


Figure 5-22(a). External Short Circuit Test, WAMH22

# 3 Month Storage @ R/T, (page 2 of 2)

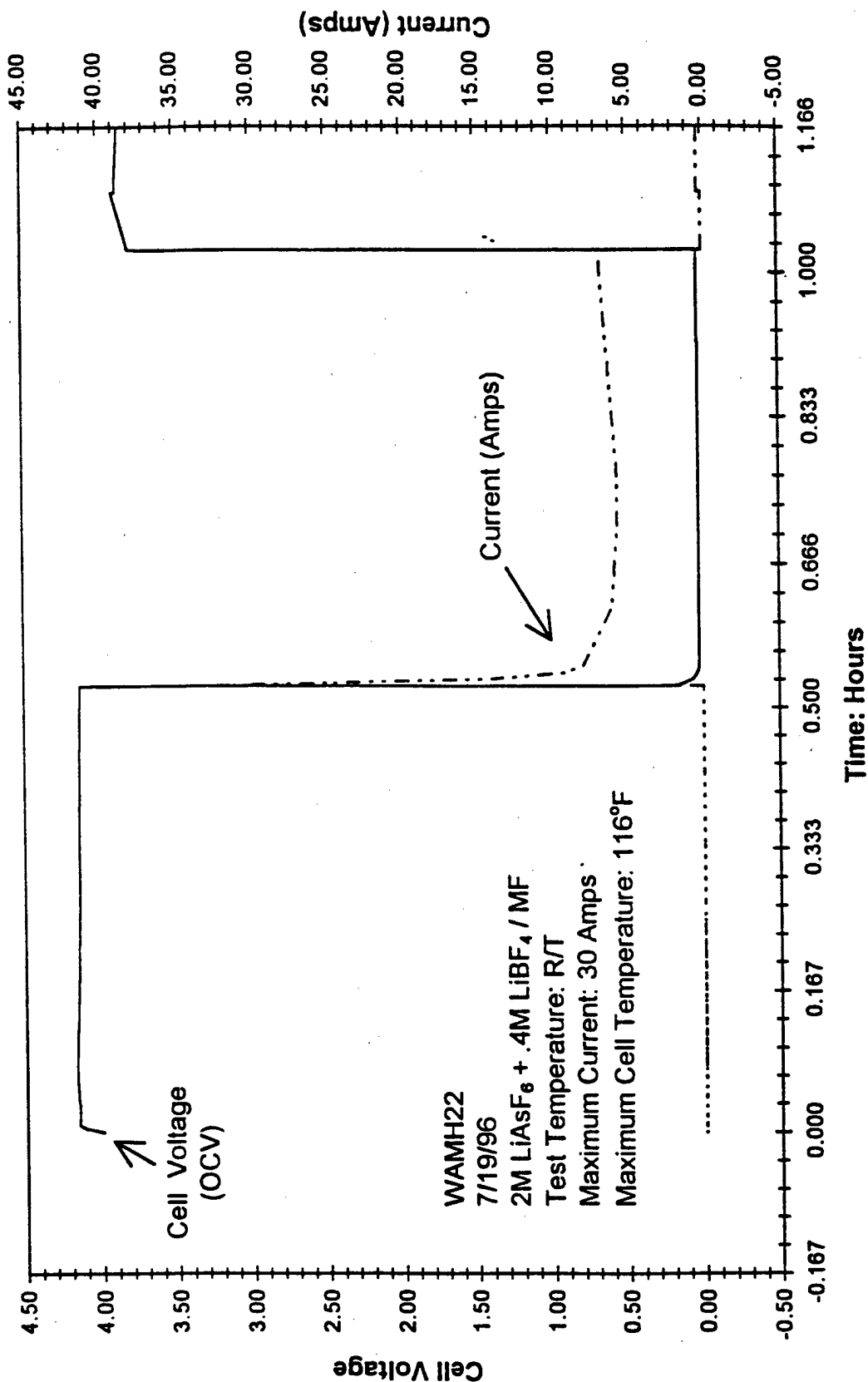


Figure 5-22(b). External Short Circuit Test, WAMH22



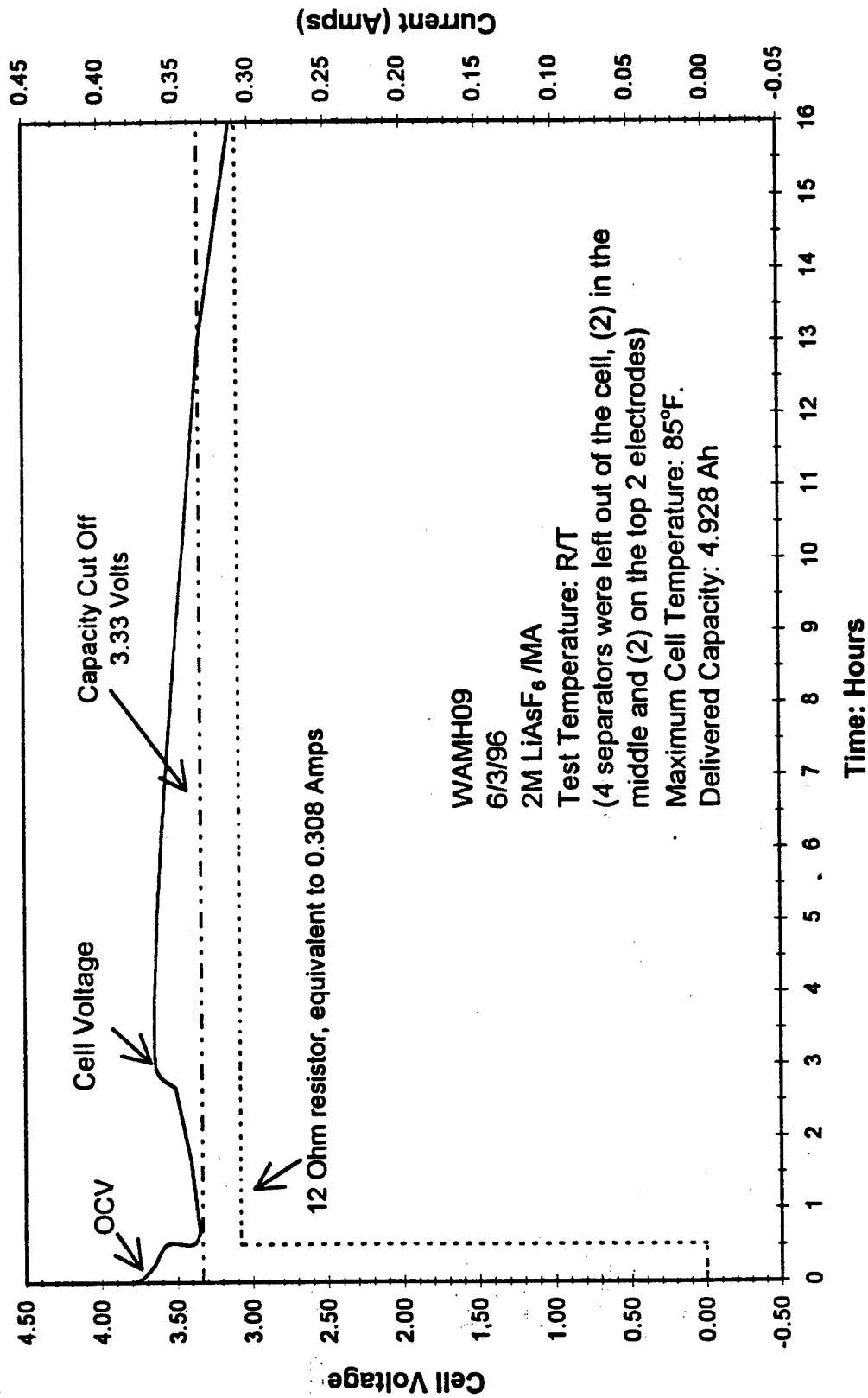


Figure 5-23. Internal Short Circuit Test and Capacity Discharge Profile, Cell WAMH09

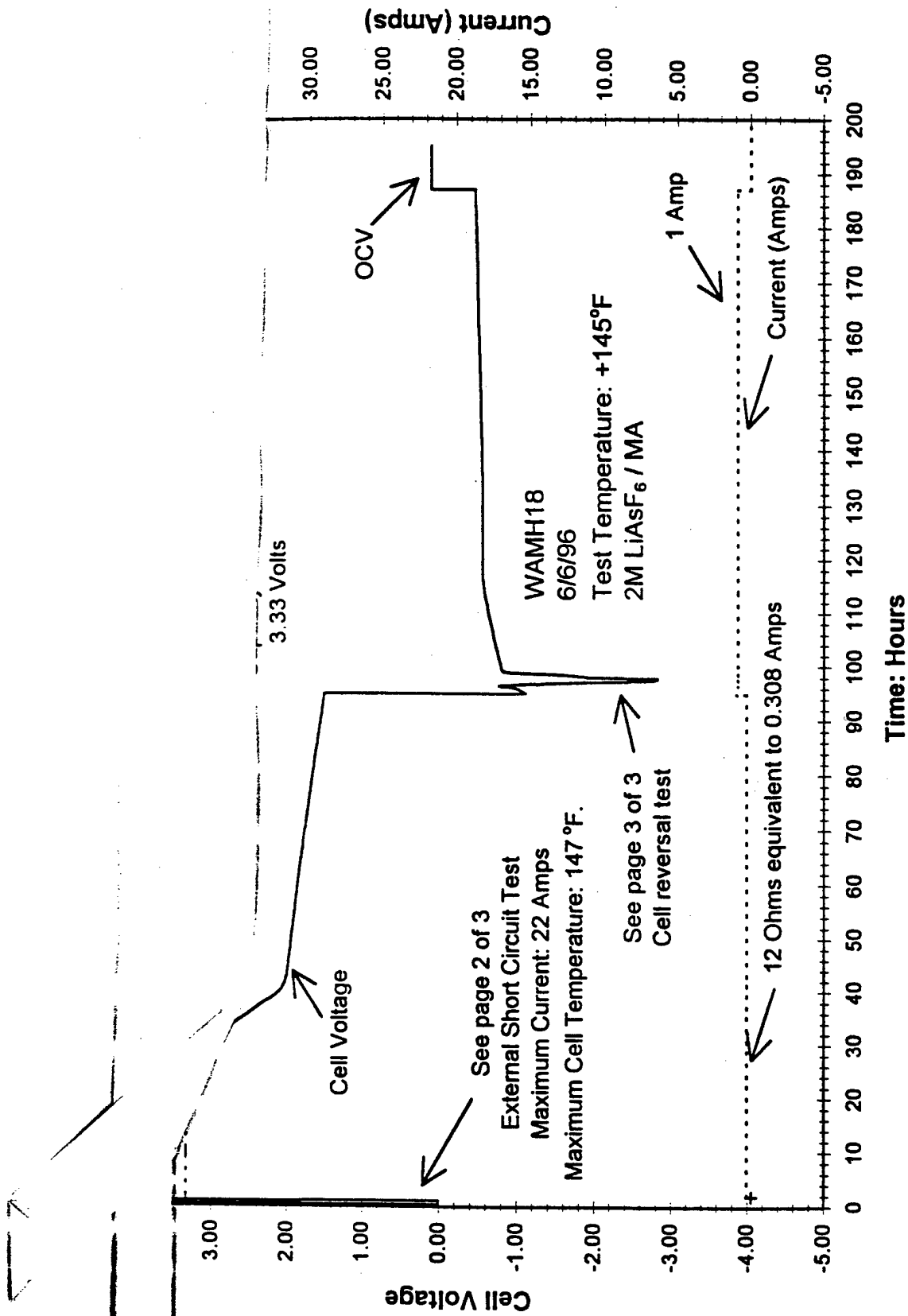


Figure 5-24(a). Short Circuit and Cell Reversal Test, WAMH18

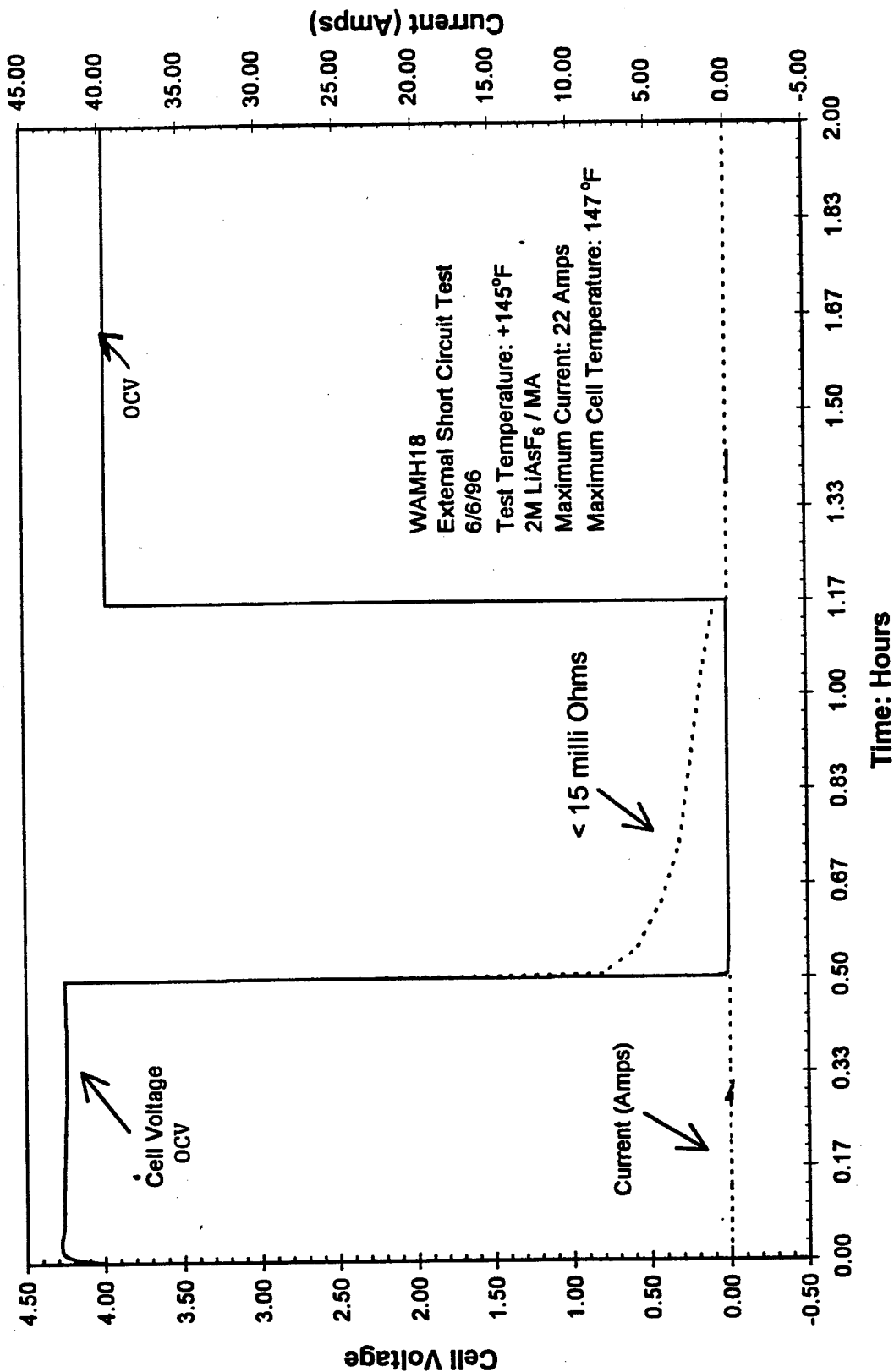


Figure 6-24(b). Short Circuit and Cell Reversal Test, WAMH18

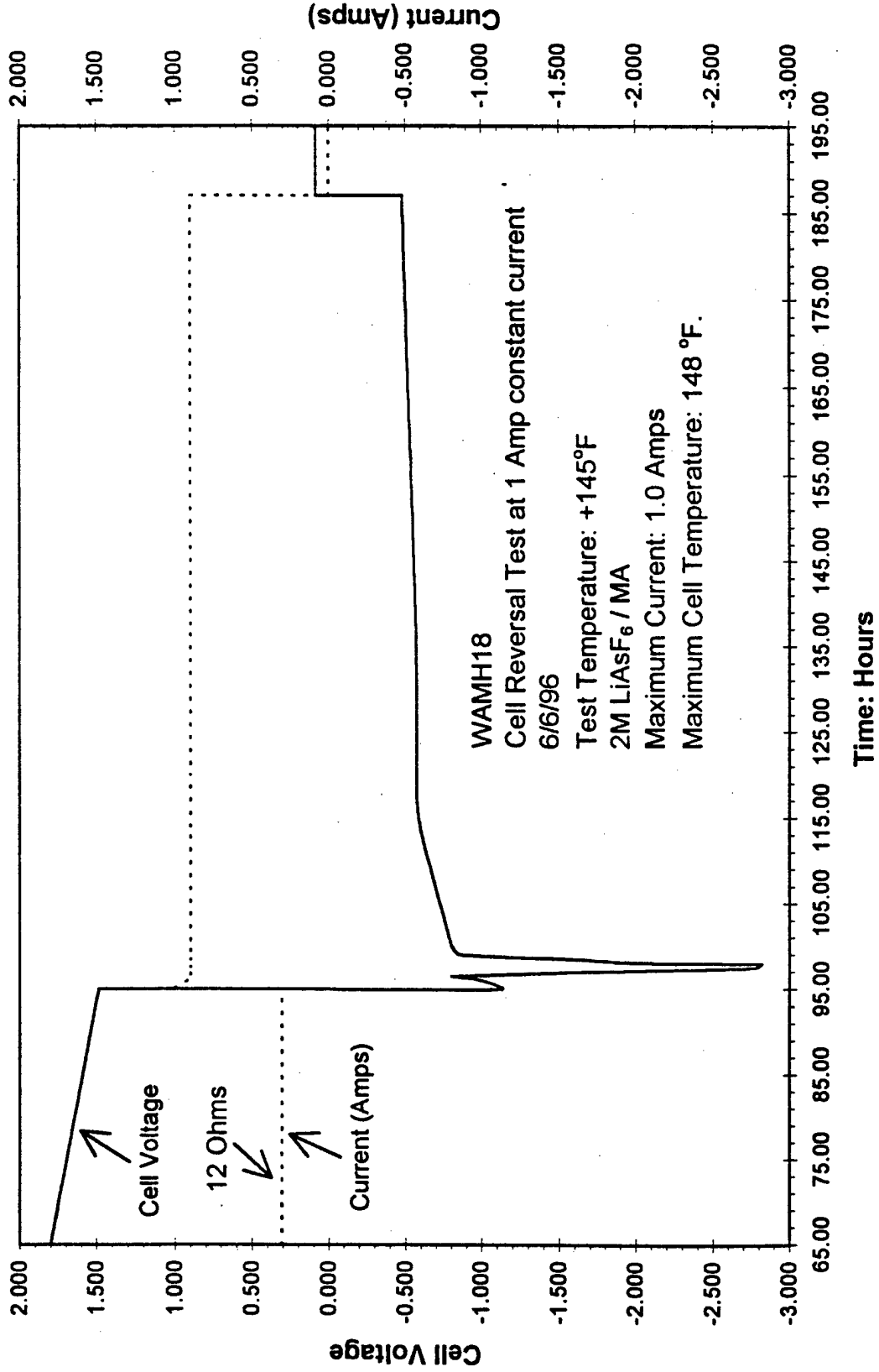


Figure 5-24(c). Short Circuit and Cell Reversal Test, WAMH18

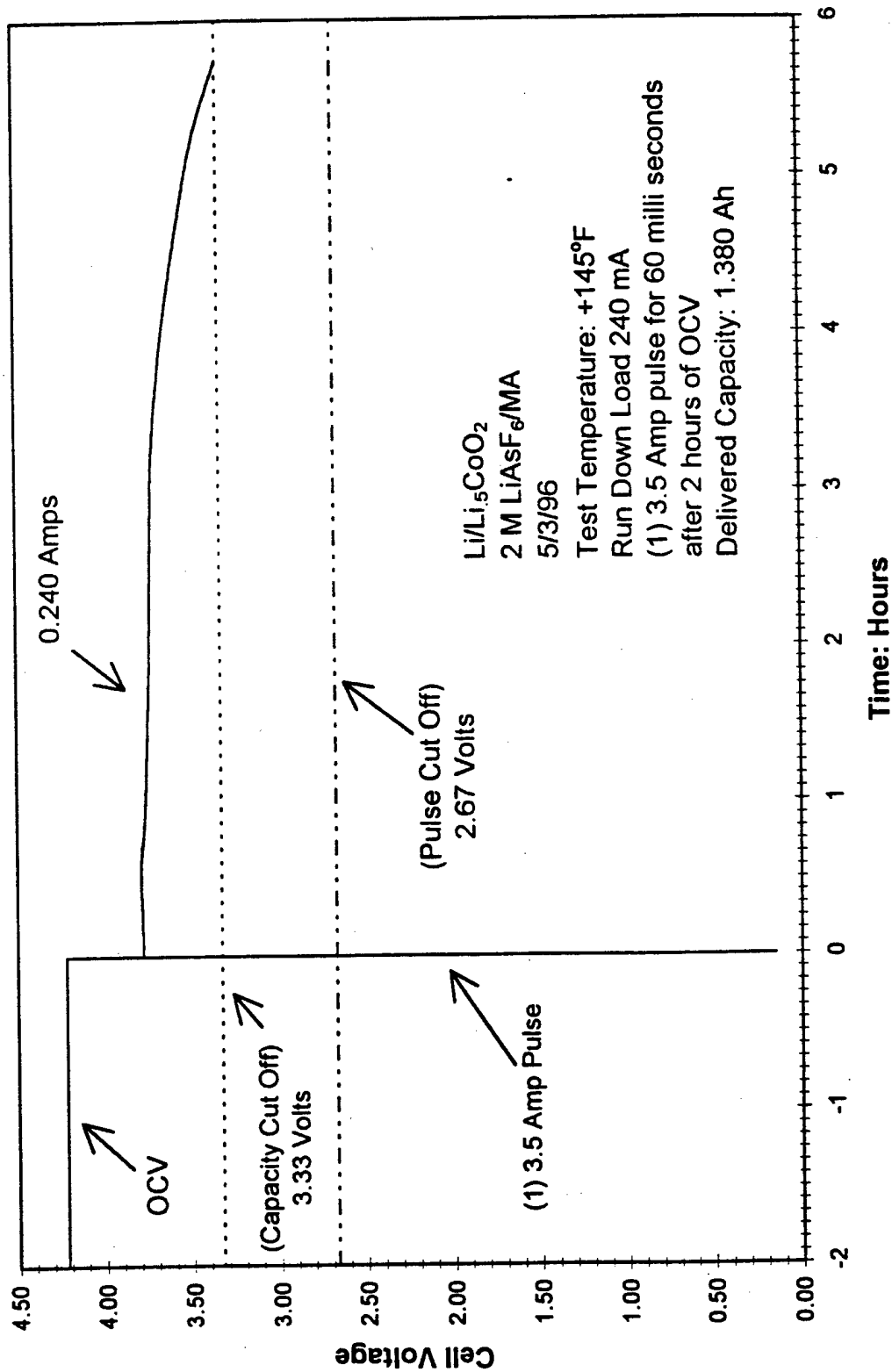


Figure 5-25. Abuse Test, Activated with 10% Electrolyte, WAMH06

## Chapter 6

### Studies

Alliant Techsystems Inc. committed several engineering studies to further the information base on the HWAM battery. Some of the studies were directed toward maximizing power of a reserve battery design beyond the current values while restricting the battery to the space allotment of Specification No. 29224A (Figure 1-1). The studies are listed below and described further in this chapter.

- Cell Improvement Studies
- Comparison of  $\text{Li}_{0.5}\text{CoO}_2$  with Thionyl Chloride ( $\text{SOCl}_2$ ) performance and safety
- Battery Life-Expectancy, reserve and active
- Battery Disposal and Pollution Prevention
- Battery Projected Unit Price Cost
- Battery Design Analysis
- Capacity Calculations for an Active Battery Design
- Capacity Required by  $\text{SOCl}_2$  Battery for Depassivation Pulses
- Reserve Battery Concept with External Reservoir

#### Cell Improvement Studies

Building an hermetically sealed, HWAM configured cell in the laboratory is time consuming because of the lack of production tooling and automation. At the same time, many choices are available to the designer for materials selection. Design choices need to be made rapidly because of schedule constraints. The selection process during cell design is based on experience; then, the most likely materials are tried in prototype cells. A fast approach is to experiment with a smaller cell configuration to eliminate the cost of trying every variable in full-size cell hardware. This was the path chosen on this program. Fortunately, a very good small cell, a modified Alliant Techsystem's production cell, Picatinny Arsenal Cell 9275567 (Figure 5-1), was an excellent choice for this work. It has hermetic construction and lends itself to modification by using alternate materials. The cathode, for instance, a mixture of vanadium oxide and graphite is constructed by pressing. Processing of the HWAM cathode, a mixture of cobalt oxide and carbon, is nearly identical. As a whole, the validity of choosing the Picatinny cell as the test vehicle is a good one. Only two attributes are not accurately matched with this test cell. They are:

The activation methods - via a glass ampul *in situ*, for the modified ATK G2666.  
The electrodes are wetted once the ampul is broken. In the case of the HWAM

cell, a remote reservoir feeds the electrodes once a gas pressure driver ruptures a metal diaphragm. The pressure-driven electrolyte conceivably wets the electrodes rapidly, as opposed to the capillary action electrolyte feed of a broken ampul.

Electrode compression - The modified ATK G2666 is constructed bobbin style, without positive pressure on the electrode sandwich. The HWAM cell is a stacked arrangement of flat plates that receive a positive compression when the case cover is welded in place. However, compression was kept to a minimum.

Physical comparison between the two cells is made in Table 6-1. The table shows that the current density is identical for the two cells as well as being close in gravimetric parameters such as the cathode specific capacity. The variables evaluated were: temperature, separator type, cathode mix ratio and electrolyte type.

**Table 6-1. Physical Comparisons**

Attribute	HWAM	G2666 (Modified)
Cathode Area / Cell (cm <sup>2</sup> )	729.2	5.24
Cathode Mix Wt./Cell (grams)	150	1.45
Cathode (Li <sub>x</sub> CoO <sub>2</sub> ) Wt./Cell (grams)	132.3	1.28
Cathode Volume/Cell (cm <sup>3</sup> )	49.9	0.428
Cathode Thickness (inches)	.027 (per side)	.030
Cathode Density (grams mix/cc)	3.0	3.39
Cathode Loading (grams mix/cm <sup>2</sup> )	0.206	0.277
Cathode Capacity (mAh/cm <sup>2</sup> )	24.5	33.0
Lithium Area/Cell (cm <sup>2</sup> )	800.6	3.94
Lithium Weight/Cell (grams)	6.5	.054
Lithium Thickness (inches)	.006 (per side)	.010
Lithium Capacity (mAh/cm <sup>2</sup> )	31.4	52.9
Defining Area/Cell (cm <sup>2</sup> )	729 (cathode)	3.94 (anode)
Defining Capacity (mAh/cm <sup>2</sup> )	28.5 (cathode)	33.0 (cathode)
Cell Capacity (Ah)	17.9	0.121
Current (c.d.) @ 400 mA (HWAM)	400 mA (.55 mA/cm <sup>2</sup> )	2.16 mA (.55 mA/cm <sup>2</sup> )
Current (c.d.) @ 3.75 Amps (HWAM)	3,750 mA (5.14 mA/cm <sup>2</sup> )	20.27 mA (5.14 mA/cm <sup>2</sup> )

The first test series evaluated three types of separators which were: Celgard 2300, Veretek 141-583, and Whatman BSB-3DA. Two different mix ratios of Li<sub>x</sub>CoO<sub>2</sub> and carbon graphite were employed. The ratios compounded were one of 90%-10% and 81%-19% of Li<sub>x</sub>CoO<sub>2</sub>/Graphite. Graphite is added for conductivity, but it displaces Li<sub>x</sub>CoO<sub>2</sub>. Two different current density levels were evaluated. They were 0.5 mA/cm<sup>2</sup> corresponding to HWAM background load rates and 5.0 mA/cm<sup>2</sup> which corresponds to HWAM pulse load rates (3.75 amperes). Four test temperatures were also a part of this test series, 28°F, 75°F, 0°F, and -25°F

(See Figures 6-1 through 6-9). Mix ratios of  $\text{Li}_x\text{CoO}_2$  and graphite made no significant difference in performance. High percentages of graphite reduce the cost of the battery since  $\text{Li}_x\text{CoO}_2$  is an expensive product. Using a non-microporous separator such as Veretek or Whatman does limit the battery to being primary and not capable of recharges. Other microporous separators would need to be identified for a rechargeable HWAM battery.

The test results showed clearly that non-woven separators, i.e., Veretek or Whatman, were superior to Celgard for electrical activation from the reserve state and overall discharge performance.

### **$\text{Li}_{0.5}\text{CoO}_2$ COMPARISON WITH $\text{SOCl}_2$**

Prior to developing the  $\text{Li}/\text{Li}_x\text{CoO}_2$  system to power the HWAM, the Army developed  $\text{Li}/\text{LiSOCl}_2$  for this application. A specific advantage of  $\text{Li}/\text{Li}_{0.5}\text{CoO}_2$  electrochemistry over  $\text{Li}/\text{SOCl}_2$  is due to the higher load voltage, 3.85 volts versus 3.4 volts. The open circuit voltage in both cases is about 0.2 volts higher. Lithium anodes passivate with time when exposed to  $\text{SOCl}_2$  at open circuit or low rate discharge, unless extremely low. A voltage dip occurs at the beginning of discharge unless the passivation has been removed. That can be done by applying a high rate discharge pulse. Such pulses are shown in Figure 2-3. The  $\text{Li}/\text{LiCoO}_2$  system does not require depassivation pulses. Furthermore, lithium/lithium cobalt dioxide is safer than lithium/thionyl chloride for all the reasons outlined in the Safety Study attached as Appendix D.

The thionyl chloride system is not rechargeable. While  $\text{Li}/\text{Li}_x\text{CoO}_2$  can be recharged. This was demonstrated in this work (See Section 5-1 and Figure 5-4). Furthermore, under the base contract, of which this work was an option item,  $\text{Li}/\text{Li}_x\text{CoO}_2$  was developed as a rechargeable system.<sup>1</sup> It is being developed for the Navy for rechargeable propulsion power, specifically as prismatic 100 Ah cells. Those cells use a microporous separator. The rapid rise time required by HWAM negated a microporous separator because it is slow to wet. Microporous separators would be needed for rechargeability. Therefore, further development work would be required to develop a separation system that would permit rapid rise time and rechargeability.

Lithium/thionyl chloride, on the other hand, has better rate capability than does lithium/lithium cobalt oxide. The difference is at least an order of magnitude in current density, i.e., 3-4  $\text{mA}/\text{cm}^2$  for  $\text{Li}/\text{LiCoO}_2$  and 30-40  $\text{mA}/\text{cm}^2$  for  $\text{Li}/\text{SOCl}_2$ .<sup>2</sup> Energy density is another advantage of  $\text{Li}/\text{SOCl}_2$ . Practical values of 80 Wh/lb for  $\text{Li}/\text{LiCoO}_2$  versus 200 Wh/lb for  $\text{Li}/\text{SOCl}_2$  in 100 to 200 ampere-hour cell sizes. Nevertheless, the  $\text{Li}/\text{LiCoO}_2$  system is sufficiently energetic for HWAM.

Both  $\text{Li}/\text{LiCoO}_2$  and  $\text{Li}/\text{SOCl}_2$  have excellent power capability, and both have good low temperature performance, which make them the primary electrochemistry choices for HWAM. Figures 6-10 and 6-11, and Table 6-2 give comparison data between  $\text{LiCoO}_2$  and  $\text{SOCl}_2$ . The  $\text{SOCl}_2$  comparisons are for two very different embodiments of the electrochemistry. They are both reserve cells, but the HED battery (Alliant Techsystem's G2666B1), a version of the Alliant's G26666 (Figure 5-1) based on the oxyhalide cathode instead of vanadium oxide, has a 1 Watt-



hour capacity while the SPM unit (Alliant Techsystem's G3070A2) is a 4000 Watt battery for powering sonobuoys. These batteries have been produced on production lots. Further information on these power sources may be found in Appendix E, taken from an Alliant Techsystems marketing brochure.<sup>4</sup>

### **Battery Life Expectancy**

Life expectancy for  $\text{Li/Li}_{0.5}\text{CoO}_2$  batteries is excellent as shown by real time test data of hermetic cells. The Picatinny cell 9275567, modified with the HWAM cathode of precharged lithium cobalt dioxide, was activated and placed on a slow rundown load (150K-ohms) equivalent to the HWAM 7 months background rate. The cell ran for 7.13 months (5,136 hours). This was then compared with a fresh cell of the same type that was activated and discharged at a fast rate, 31 hours (900 ohms). The fresh cell yielded 132 milliampere-hours of capacity, whereas the slowly discharged cell yielded 134 milliampere-hours of capacity. Essentially, no loss in life expectancy for slow, long time use. These tests were conducted at room temperature and are plotted together in Figure 6-12. No tests were conducted on cells that were first activated, and then left on open circuit for 7 months, followed by a fast discharge. However, in many ways the test presented is a better representation of HWAM requirements. Life tests at temperature extremes also need to be conducted in a future program.

### **HWAM Active $\text{Li/Li}_{0.5}\text{CoO}_2$ Battery**

One of the tasks requested during the development of the HWAM  $\text{Li/Li}_{0.5}\text{CoO}_2$  battery was an evaluation of the capacity of an active battery using the same volume constraints as the HWAM Reserve Battery. Nominal capacity for the reserve battery was 14 ampere-hours. Using the volume displaced by the reservoir for additional electrode space, an active battery was designed with a cross-section as shown in Figure 6-13. The component electrode design summary is shown in Table 6-3. The nominal capacity expected from this design is 35-ampere-hours. The weight budget for the active battery design is shown in Table 6-4. Total battery weight is 4.5 pounds. If a weight maximum of 3.0 pounds (present specification, see Table 2-1) were to be imposed on the battery design, then the maximum expected capacity would be 22.4 ampere-hours.

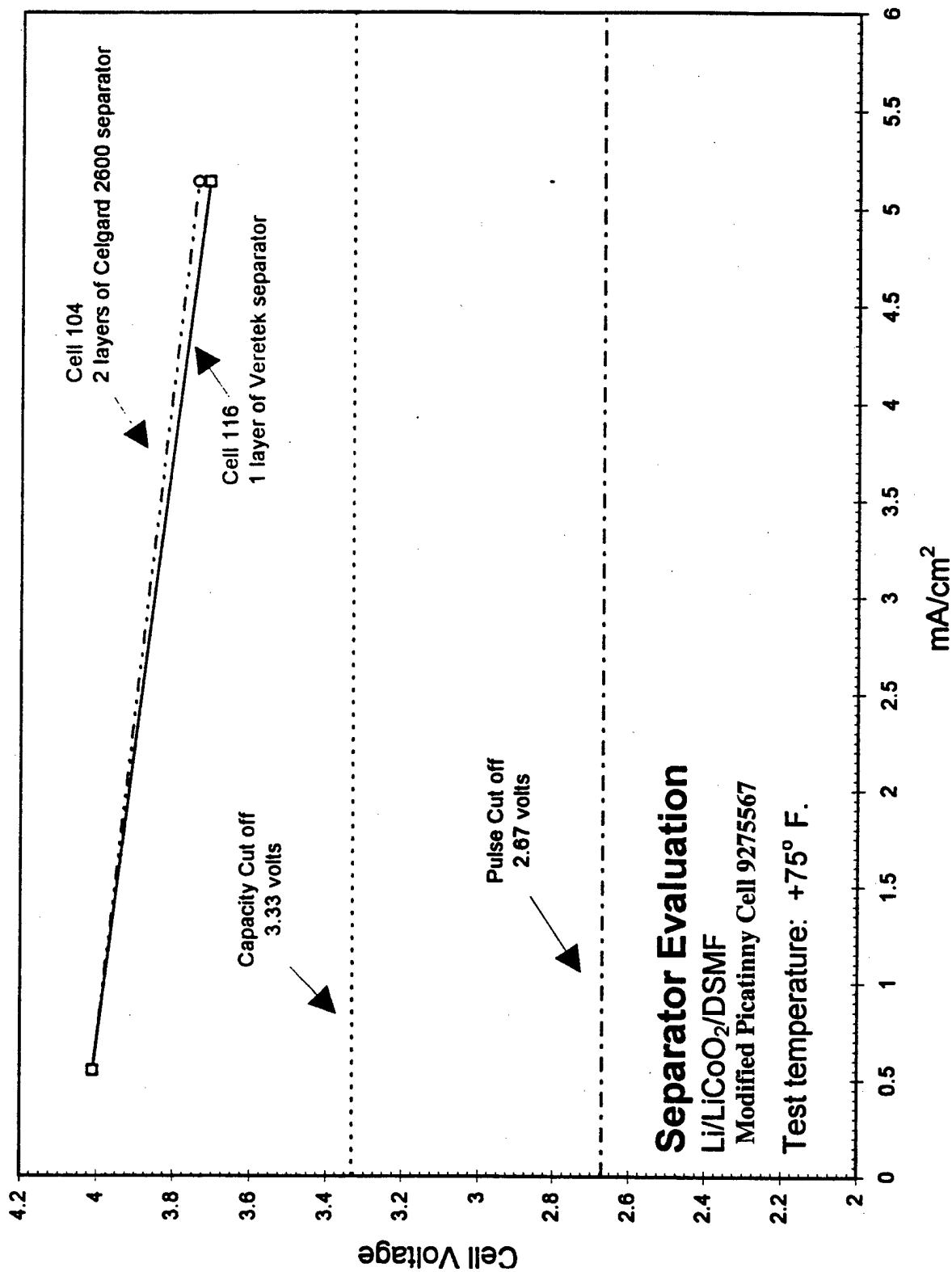


Figure 6-1. Separator Evaluation, +75°F

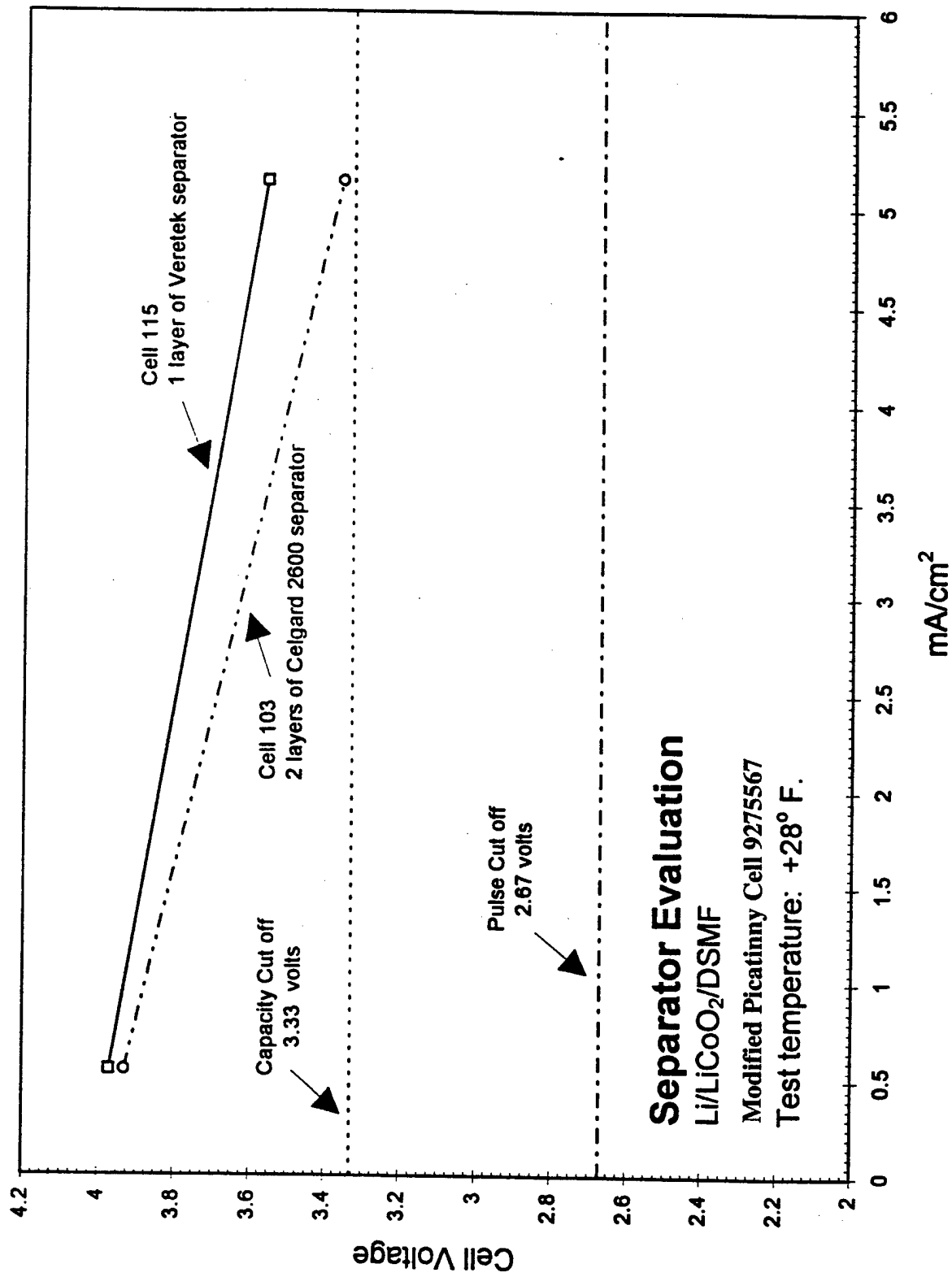


Figure 6-2. Separator Evaluation, +28°F

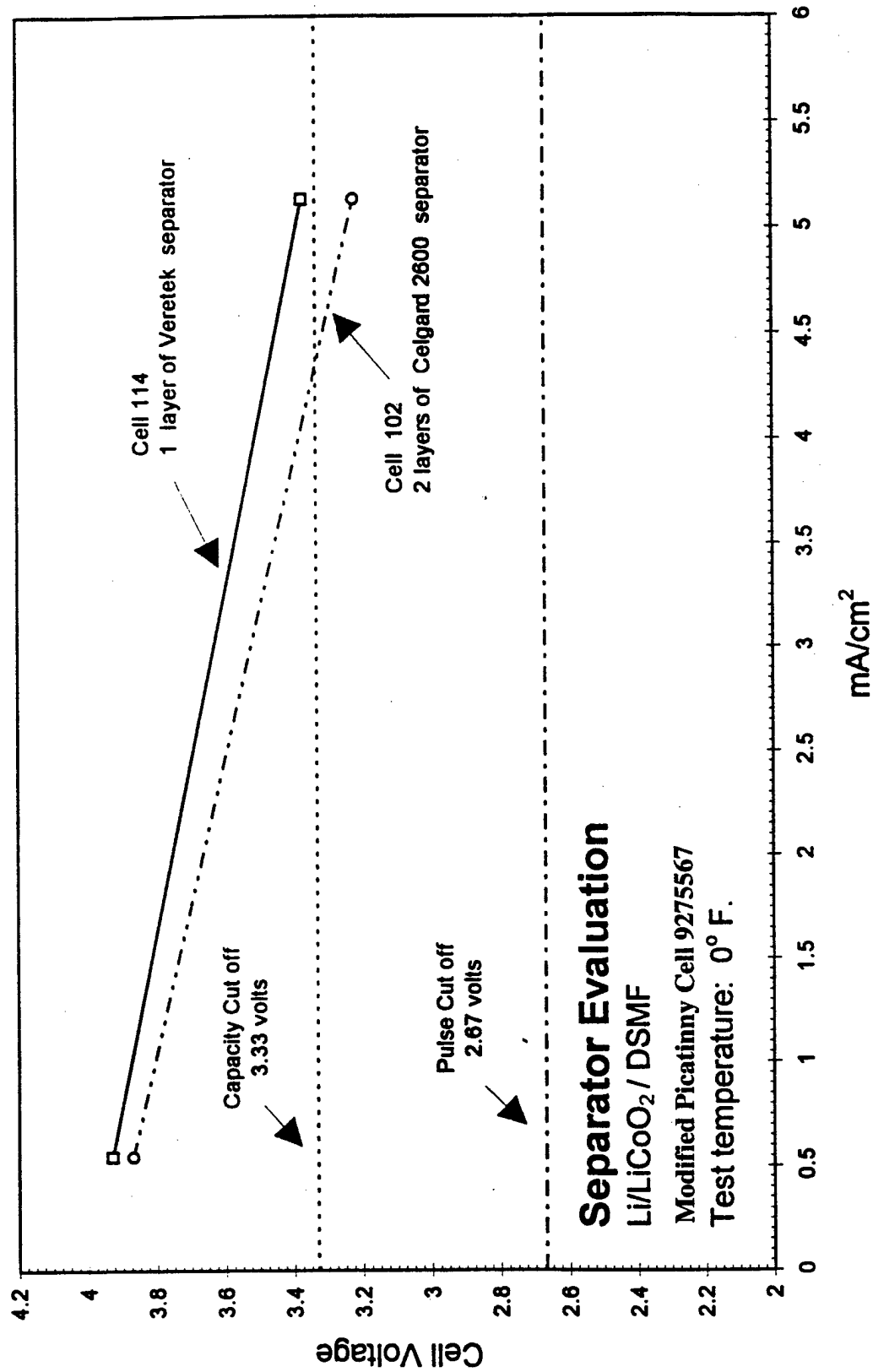


Figure 6-3. Separator Evaluation, 0° F

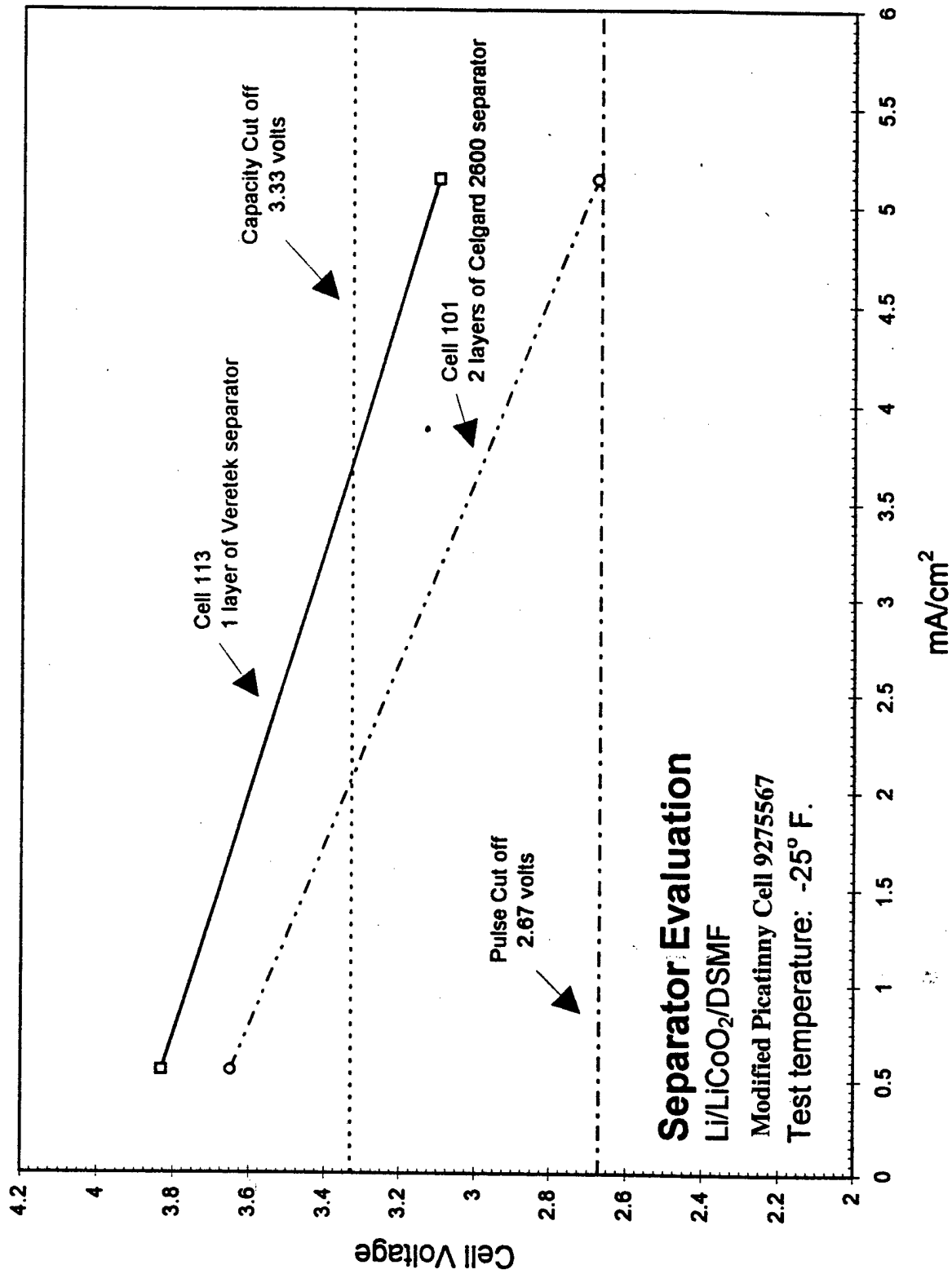
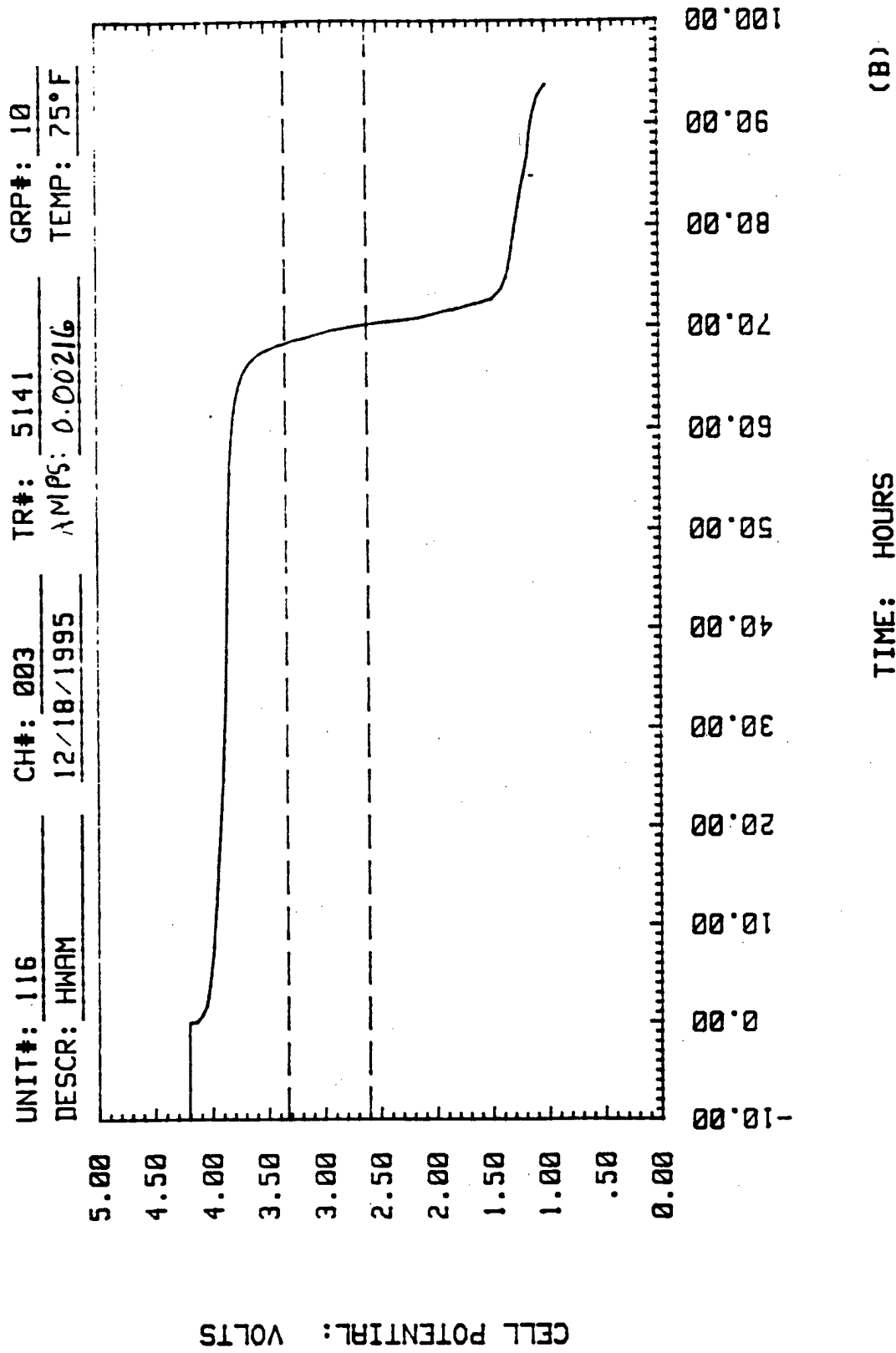


Figure 6-4. Separator Evaluation, -25°F

Figure 6-5. Modified Picatinny Cell 9275567, Li/Li<sub>2</sub>CoO<sub>2</sub>/DSMF, 1 Layer Veretek

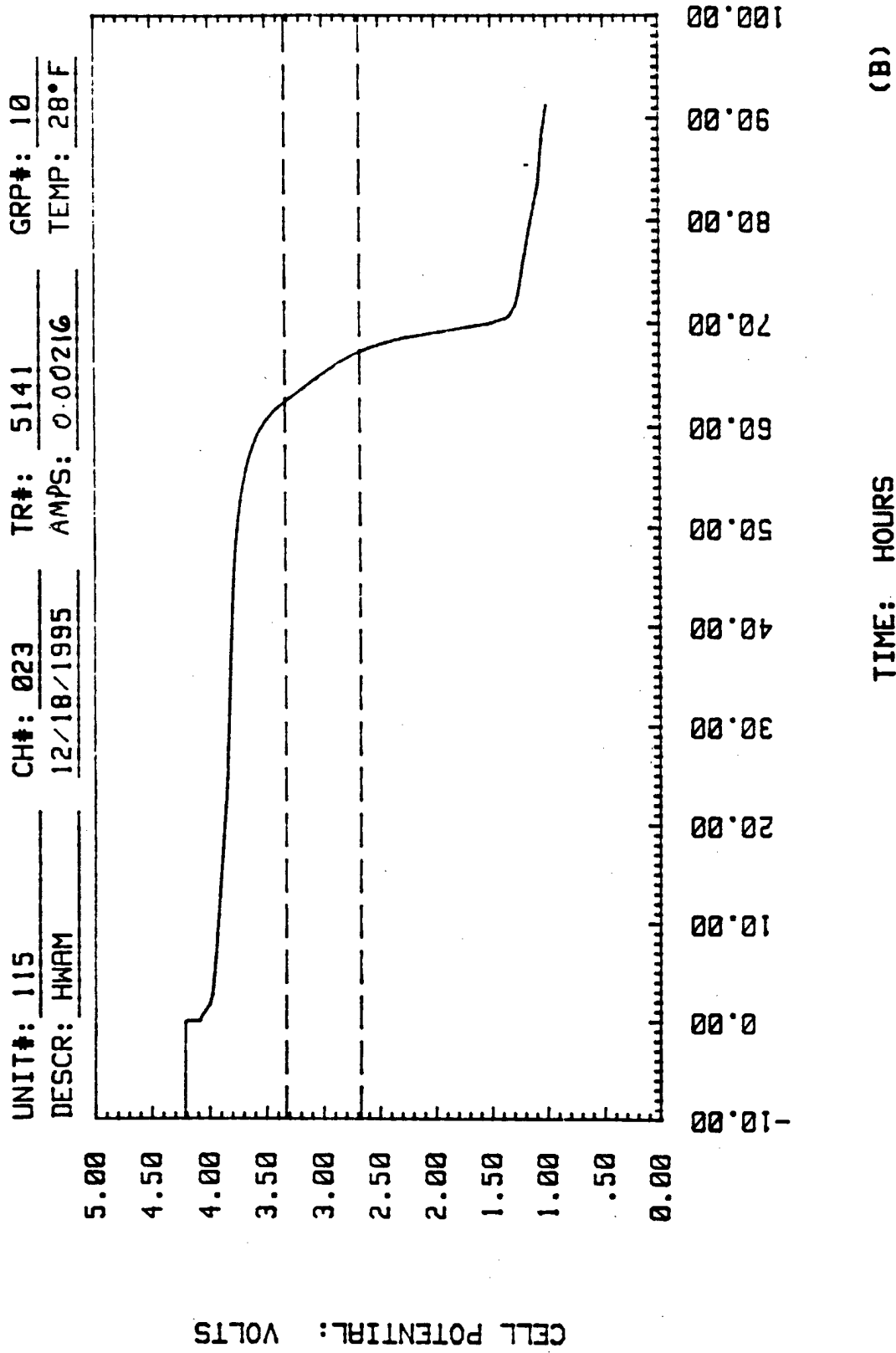
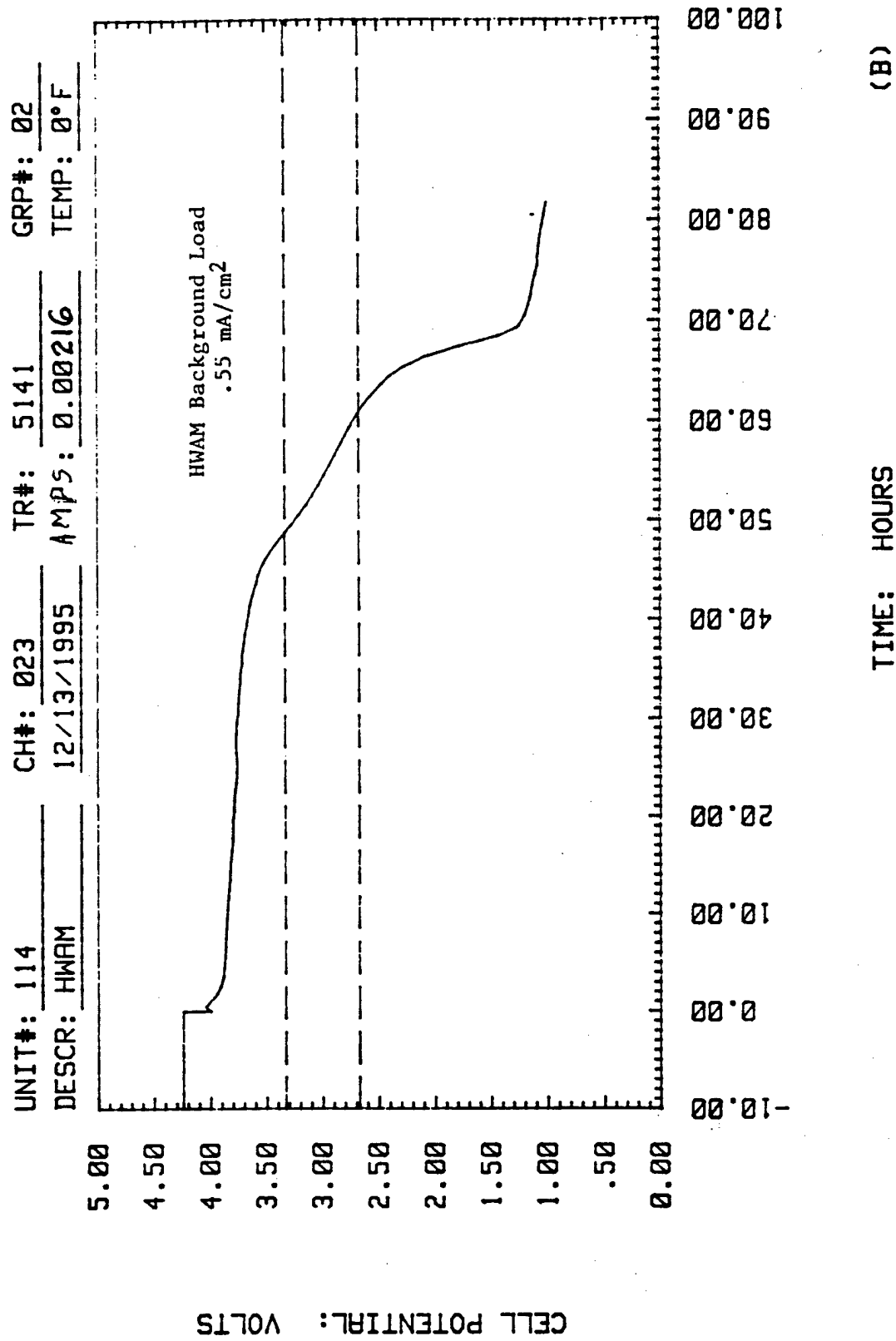
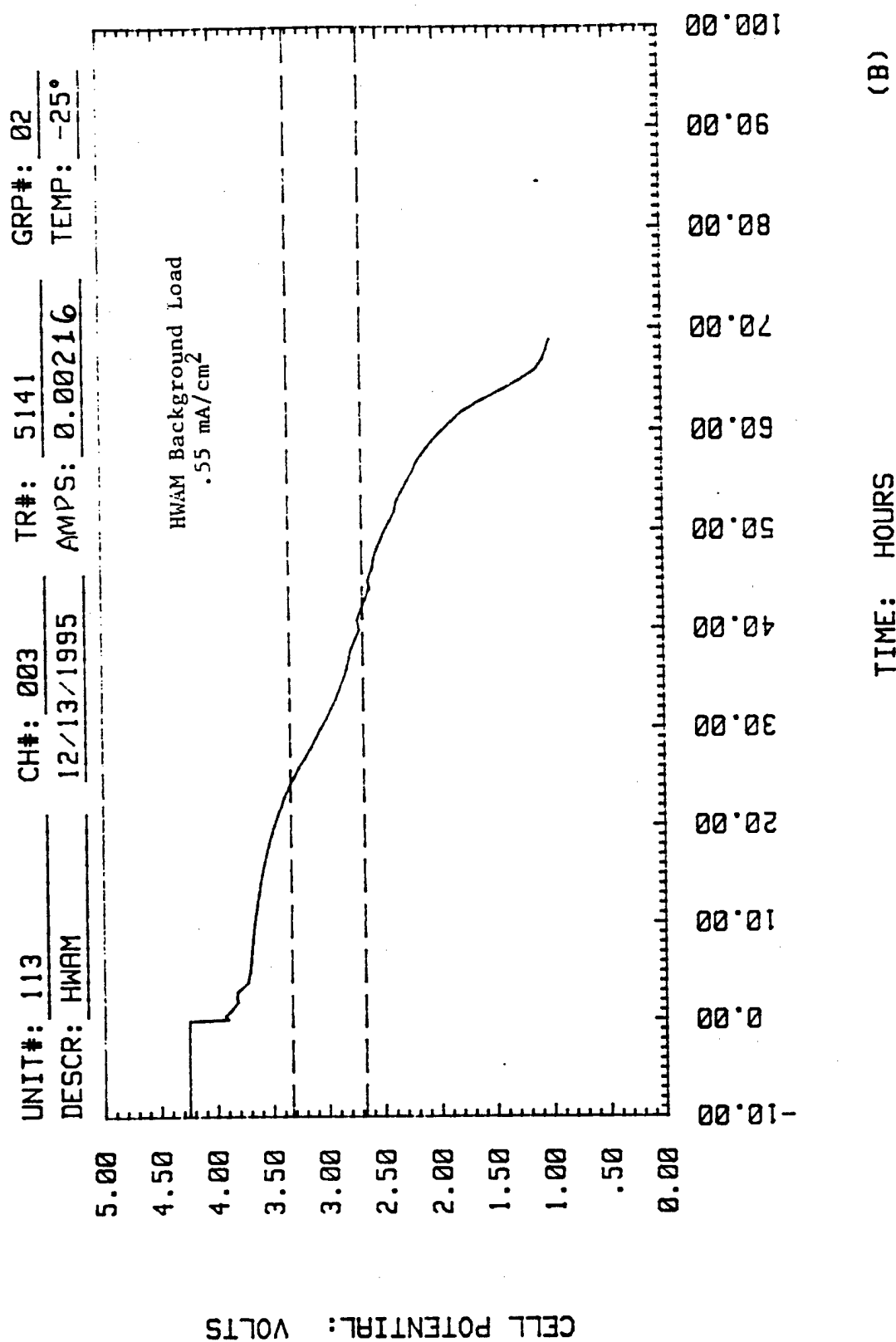


Figure 6-6. Modified Picatinny Cell 9275567, Li/Li<sub>2</sub>CoO<sub>2</sub>/DSMF, 1 Layer Veretek

Figure 6-7. Modified Picatinny Cell 9275567, Li/Li<sub>2</sub>CoO<sub>2</sub>/DSMF, 1 Layer Veretek



Figure 6-8. Modified Picatinny Cell 9275567, Li/Li-CoO<sub>2</sub>/DSMF, 1 Layer Veretek

**Modified Picatinny Cell 9275567**

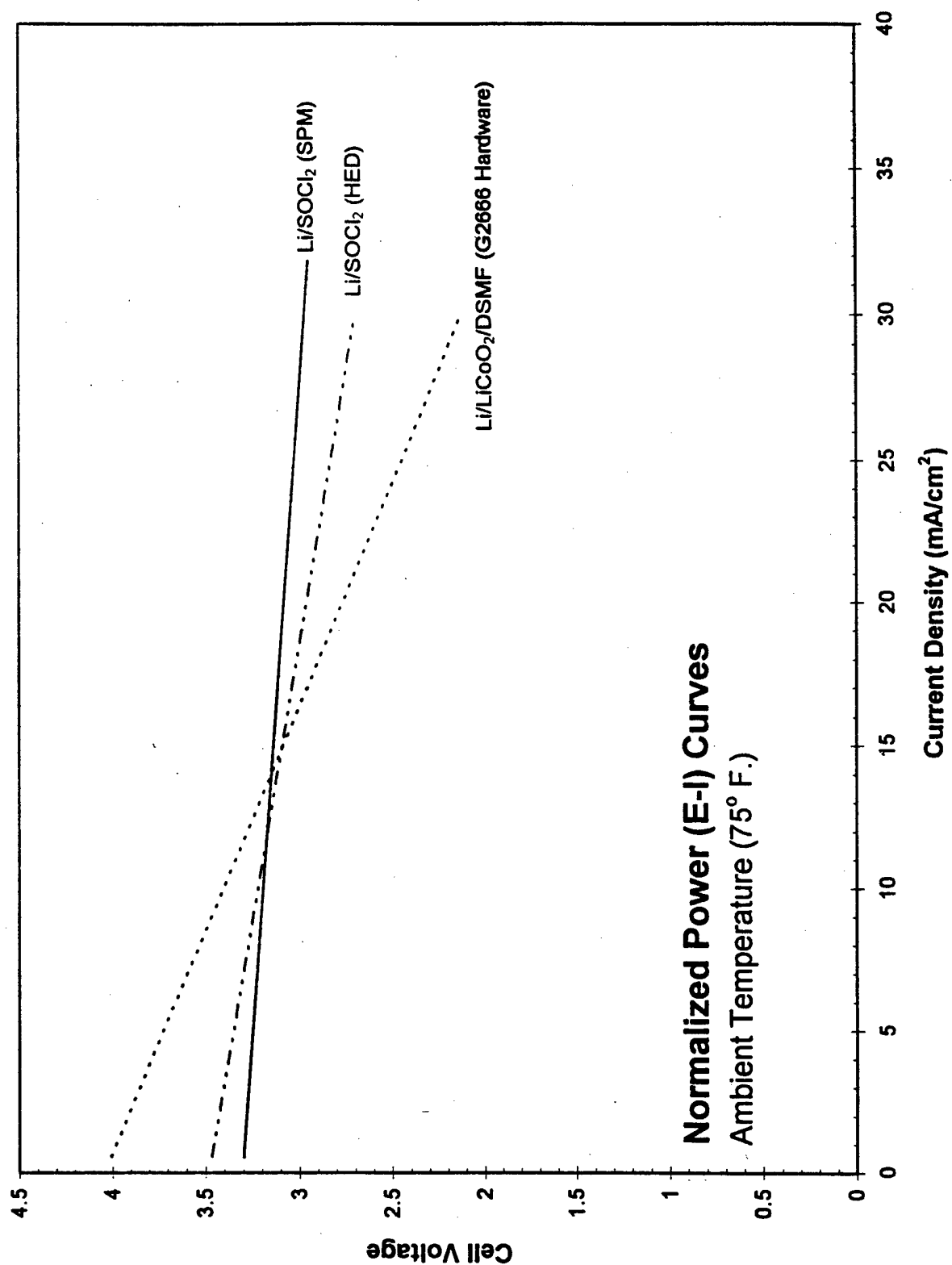
**Li<sub>x</sub>CoO<sub>2</sub> Cathode  
Veretek Separator  
DSMF Electrolyte**

**Discharged @ .55 mA/cm<sup>2</sup> (equivalent to 400mA on HWAM cell)**

Temperature Cutoff Voltage	-25°F	0°F	+28°F	+75°F
3.33 volts (10 volts)	27.8 11.1	48.2 19.3	60.1 24.0	68.6 27.4
3.0 volts (9 volts)	33.3 13.3	53.9 21.65	64.2 25.7	69.6 27.8
2.67 volts (8 volts)	42.3 16.9	61.2 24.5	67.3 26.9	70.4 28.2

Amp Hours (equivalent) for HWAM	Running Hours (Test Cell)
------------------------------------	------------------------------

**Figure 6-9. Cell Capacity Versus Cutoff Voltage**

Figure 6-10. Normalized Power Curves for Li/Li<sub>0.5</sub>CoO<sub>2</sub> and Li/SOCl<sub>2</sub>

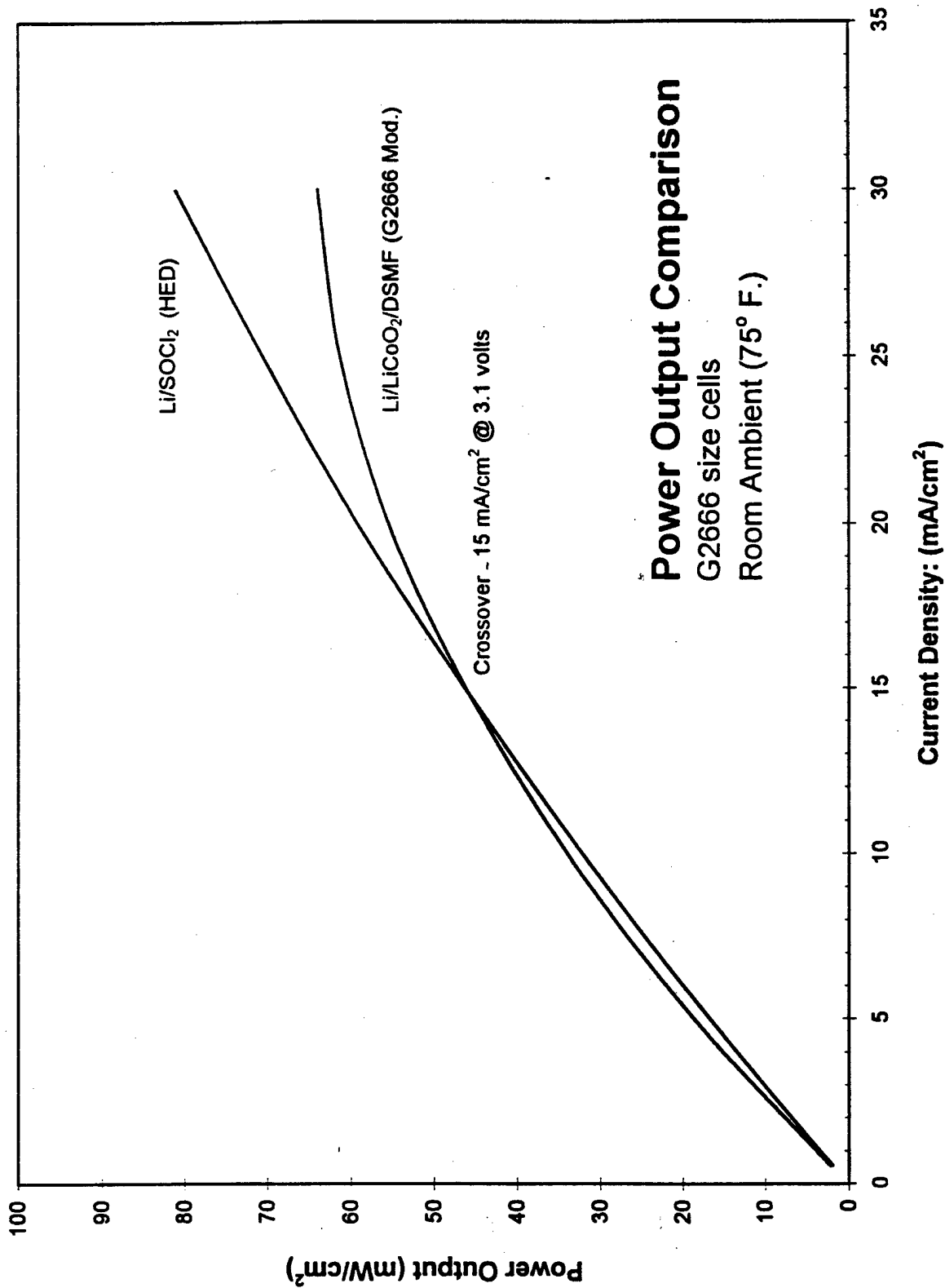


Figure 6-11. Power Output Comparison Between Li/Li<sub>0.5</sub>CoO<sub>2</sub> and Li/SOCl<sub>2</sub>

**Table 6-2. Capacity Comparison Between Li/Li<sub>0.5</sub>CoO<sub>2</sub> and Li/SOC1<sub>2</sub> in Same Size Hermetic Cells\***

**Energy Comparison**

Modified Picatinny Cell  
9275567 (Li<sub>x</sub>CoO<sub>2</sub>)  
DSMF Electrolyte  
1 Veretek Separator  
Weight: 6.33 grams  
Volume: 2.66 cc (.163 in<sup>3</sup>)

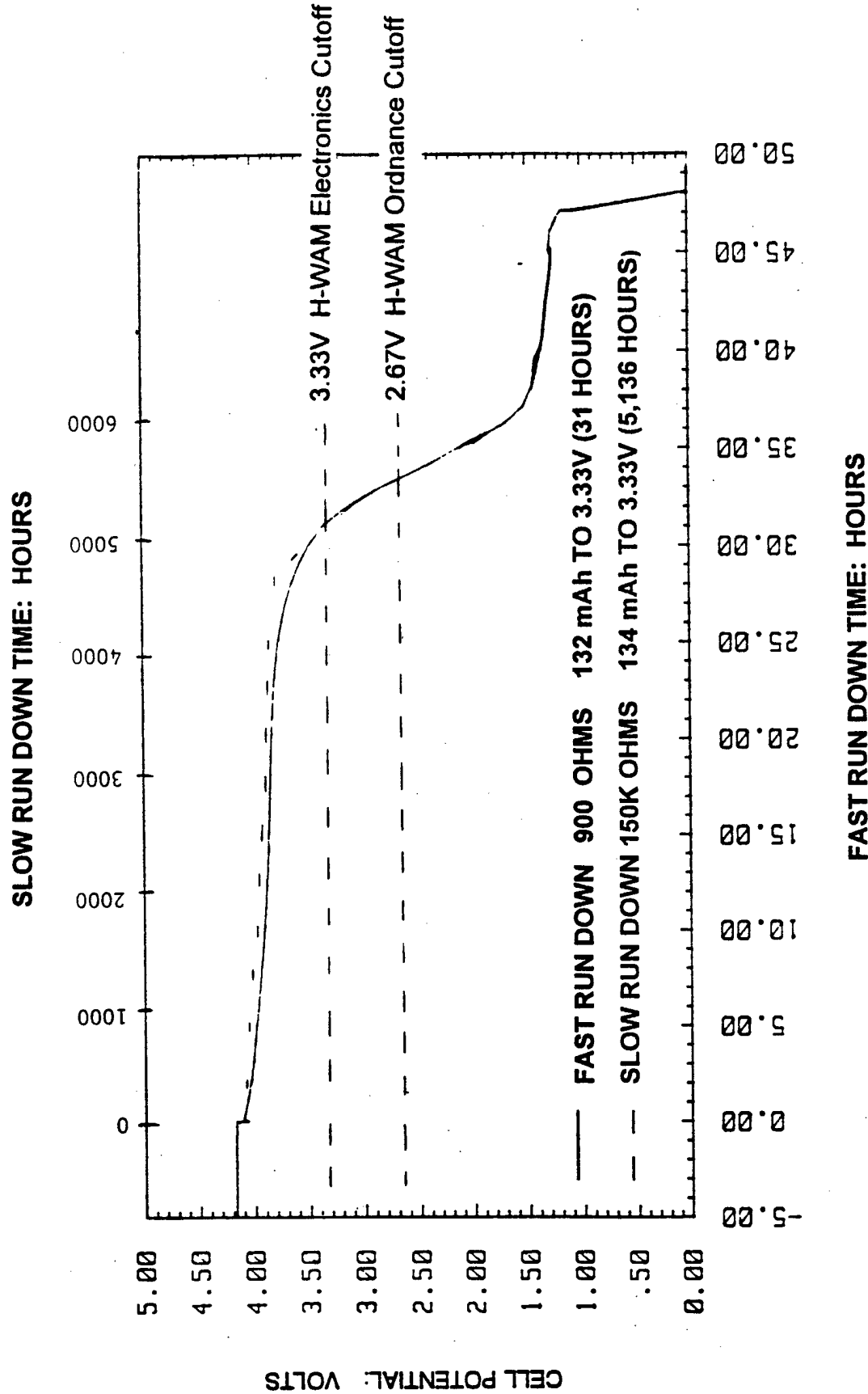
HED (SOC1<sub>2</sub>)  
SOC1<sub>2</sub> Electrolyte  
1 Glass Separator  
Weight: 5.27 grams  
Volume: 2.66 cc (.163 in<sup>3</sup>)

Discharged at 2.16 mA  
Milliamp hours to cut-off  
voltage

Temperature Cutoff Voltage	-25°F	0°F	+28°F	+75°F
3.33 volts	60.0 0.9	104.1 0.9	129.8 1.3	148.2 260.5
3.0 volts	71.9 77.3	116.4 158.5	138.7 205.2	150.3 284.3
2.67 volts	91.4 114.5	132.2 182.3	145.4 211.68	152.6 288.6

	Li <sub>x</sub> CoO <sub>2</sub> , mAh
HED, mAh	

\* Both cells have the same external dimensions and have similar construction features including the ampul reservoir.



**Figure 6-12. Fast Run Down Versus Slow Run Down of Picatinny Hermetic Cells, Picatinny #9275567 (Modified), Room Temperature**

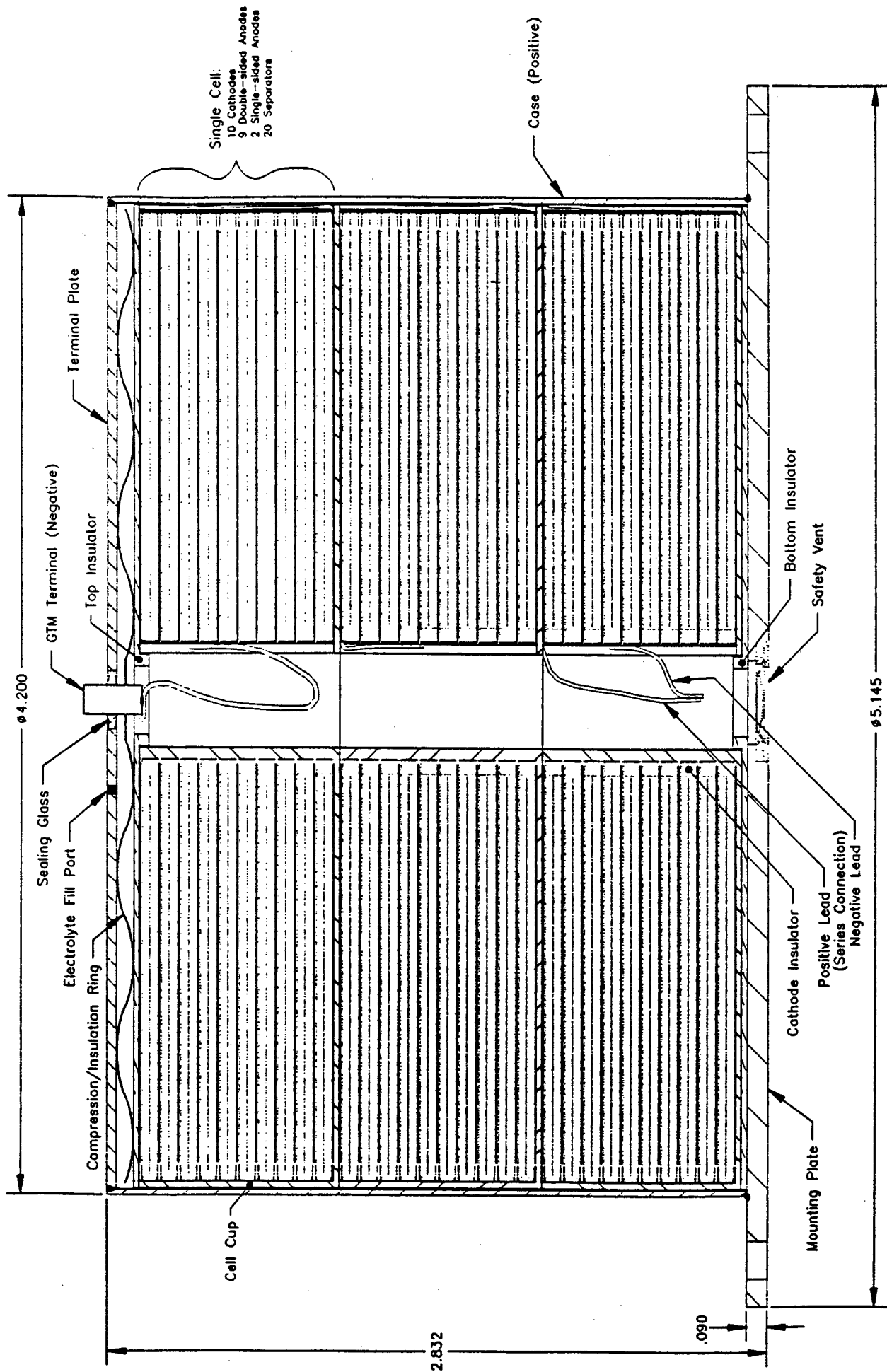


Figure 6-13. HWAM Active Battery Design

**Table 6-3. HWAM Active Battery Electrode Design**

Component	OD	ID	Thickness	Surface Area	Volume		# /Cell II	Vol /Cell	Total #
	(in)	(in)	(in)	(in <sup>2</sup> )	(in <sup>3</sup> )	(cm <sup>3</sup> )		(cm <sup>3</sup> )	
Cathode:	4.04	0.62	0.06	12.52	0.75	12.31	10	123.07	30
Anode:									
Single Sided	3.94	0.52	0.007	11.98	0.08	1.37	2	2.75	6
Double Sided	3.94	0.52	0.013	11.98	0.16	2.55	9	22.97	27
Separator:	4.08	0.50	0.005	12.88	0.06	1.06	20	21.10	60
Cathode Insulator:	0.62	0.50	0.06	0.11	0.01	0.10	10	1.04	30

**Battery Capacity:                    37.45 Ah**

**Table 6-4. HWAM Active Battery Weight Summary**

Component	Weight (g)	No./Battery	Weight/Battery (g)
Cell Cup	23.45	3	70.34
Anodes, Complete Assembly:			
Single Sided	1.26	6	7.55
Double Sided	1.82	27	49.06
Separators	0.43	60	25.64
Cathodes, Complete Assembly	36.92	30	1107.64
Electrolyte	280.22	1	280.22
Leads, Positive/Negative	3.28	6	19.66
Compression/Insulation Ring	16.22	1	16.22
Insulator, Top/Bottom	9.21	2	18.42
GTM Terminal	0.55	1	0.55
Insulator, Intra-Cell	1.76	2	3.52
Terminal Plate	70.67	1	70.67
Battery Case	117.87	1	117.87
Mounting Plate	241.42	1	241.42
Battery Vent	1.56	1	1.56
		<b>Total:</b>	2030.34 (g) 4.47 (lbs)
This active battery was designed to the same volume as the current reserve HWAM battery without regard to weight. If the battery is designed to conform to the weight restriction of 3 lbs. - 0.3 lbs., the capacity would be:			
	22.47 Ah		



**Li/Li<sub>0.5</sub>CoO<sub>2</sub> Capacity Not Lost To Depassivation Requirements**

Since Li/Li<sub>0.5</sub>CoO<sub>2</sub> cells do not passivate with storage, the need for depassivation pulses to clean-up electrode surfaces does not exist. Thionyl chloride systems do passivate and clean-up capacity contingency must be factored into battery design. For one of the study tasks, Alliant Techsystems was asked to calculate the capacity saved by not needing depassivation pulses in the Li/Li<sub>0.5</sub>CoO<sub>2</sub> HWAM battery. Calculations, given below, show that a nominal 2 ampere-hours of additional capacity are needed to compensate for passivation clean-up.

**Energy Removed - Depassivation Pulses**

Estimated Battery Voltage - 3.2 vpc x 4 = 12.8 volts

Load Resistance (Fig. 3 spec 29224A) = 2.5 ohms

Pulse Duration\* (Fig. 3 spec 29224A) = 0.5 sec.

Pulse Interval (Fig. 3 spec 29224A) = 1 every 2 hours

Days Under Load (Fig. 3 spec 29224A) = 180 days minimum

Pulse Current =  $\frac{12.8 \text{ volts}}{2.5 \text{ ohms}} = 5.12 \text{ amps}$

Amp Hours/Pulse =  $5.12 \text{ amps} \times .5 \text{ sec} \times \frac{1 \text{ hour}}{3600 \text{ seconds}} = .000711 \text{ amp hours}$

**Number of Pulses:**

$\frac{1 \text{ pulse}}{2 \text{ hrs.}} \times \frac{24 \text{ hours}}{\text{day}} \times 180 \text{ days minimum} = 2160 \text{ minimum}$

**Capacity Removed At Any Assumed Low-Rate Efficiency:**

$2160 \text{ pulses minimum} \times .000711 \text{ amp hours/pulse} = 1.53 \text{ amp hours minimum}$

However: As the rate of discharge is increased, the system deliverable capacity is lowered as a result of increasing losses due to irreversible processes occurring within the cell. The capacity reduction due to the high current (5 amp) pulses would be considerably greater than the same capacity removed at the nominal .625 milliamp standby current. Based on published data,<sup>4</sup> (5 amp) capacity would be 25-35% less than at the low standby nominal rate. Therefore, using a capacity 30% less, the resultant effect on capacity (compared with a steady low rate discharge without the depassivation pulses) would be:

$1.53 \text{ amp hrs. minimum} \times \frac{100\%}{(100\% - 30\%)} = 2.19 \text{ amp hours}$

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\* An unofficial change proposal from the HWAM device manufacturer dated 4/18/95 indicates a doubling of the depassivation pulse duration from 0.5 sec. to 1 sec. with no change in frequency or load. Under this regime the capacity removed would also double to 3.0 amp hours (180 days minimum) and the expected reduction would be on the order of 4 - 4 1/2 amp hours.

## Unit Price Cost Estimate For HWAM Reserve Battery

The estimate was based on ground rules and assumptions which are highlighted below:

- Bidding rates are Alliant Techsystems' Fiscal Year 1997.
- The HWAM Battery Design has considered ease of manufacturability. As of this writing, it has not been optimized or tooled.
- Based on input at the Milestone Meeting 2/22/96, the need for "smart control" electronics for the HWAM battery is not a priority at this time and therefore is not included in the design or costed.
- Material costs were based on actual purchase orders placed in 1995 and have not been upgraded to present day.
- Labor estimates use an 85% learning curve for projected builds prior to reaching the lowest estimated UPC. The start of the learning curve assumes having completed at least 200 pre-production units.
- Non-recurring tooling is separately funded and not included in the UPC.
- The battery lot builds are consecutive and are scheduled closely, such that workstations and tool setups dedicated to HWAM battery production do not need to be torn down. The build of 5,000 batteries follows the 3,000 battery build which follows the 1,000 HWAM Reserve Battery build.

The Unit Price Cost goals are shown below for the quantities listed:

first 1,000 units	\$3,000 each
following 3,000 units	\$2,000 each
following 5,000 units	\$1,500 each

Design changes necessary to accomplish the UPC goals are:

- A common Tefzel<sup>TM</sup> molded reservoir of the type shown in Figure 6-14 but not limited to the oversized reservoir shown.
- A revised activation system of the type shown in Figure 6-14 but not limited to that configuration.
- Work with vendors to improve parts designs for producibility, which may require some vendor non-recurring cost to reduce part unit costs.
- A cathode fabrication method that is more cost effective than pressed cathodes.

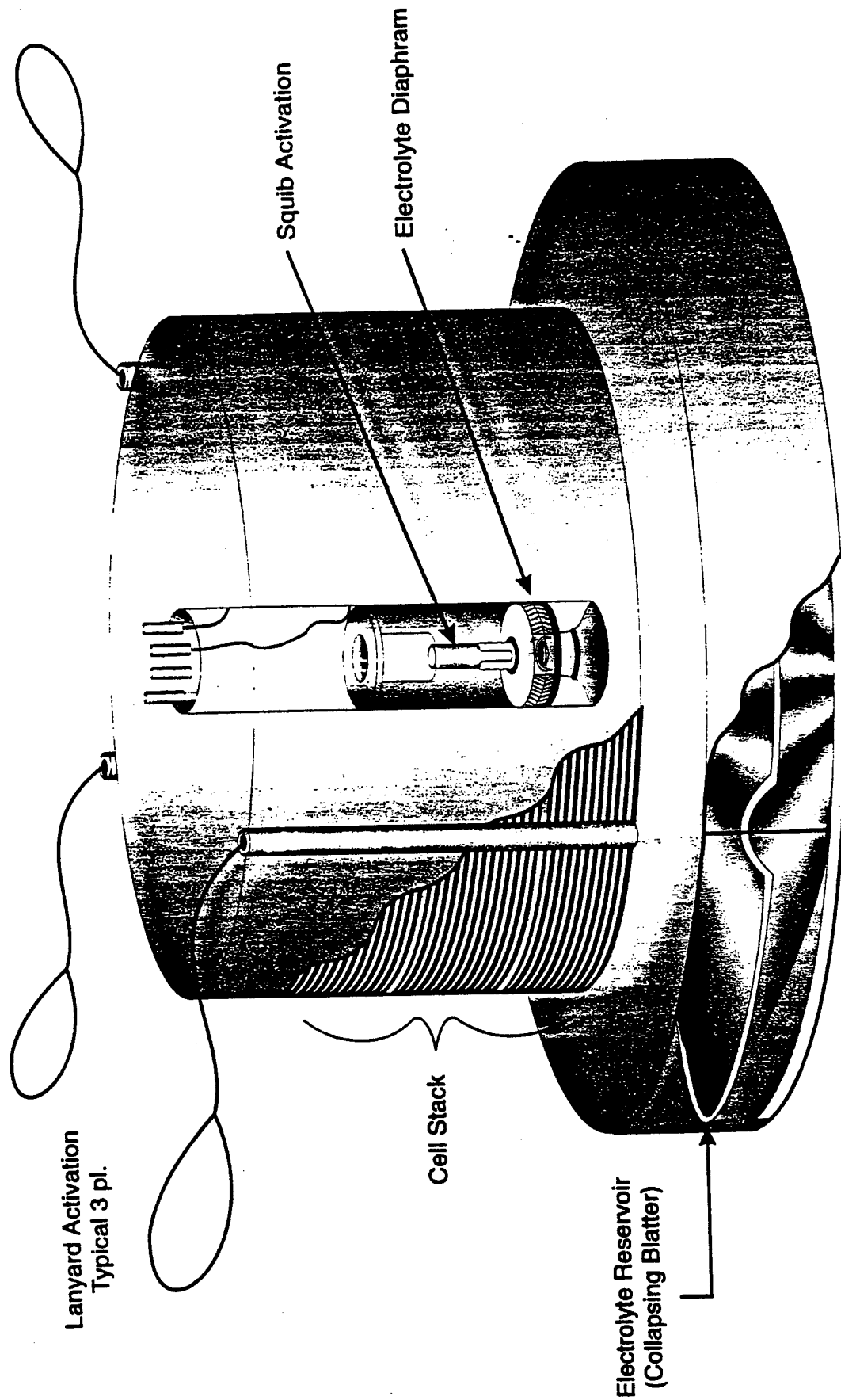
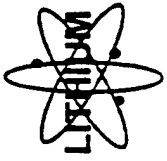


Figure 6-14. HWAM Reserve Battery, 30 Ampere-Hour Capacity

REFERENCES

1. Lin, H. P. W.; Kelly, C. J.; Chua, D. L.; Smith, P. H.; James, S. D.; and Fleischmann, C. W., "Development of a 30-Ampere-Hour Lithium/Lithium Cobalt Oxide Rechargeable Battery," **NAVSWC TR 91-184**, 30 Sept 1994.
2. Lin, H. P. W.; Kelly, C. J.; Chua, D. L.; Smith, P. H.; James, S. D.; Murphy, T. C.; Fleischmann, C. W.; and Zoski, G. D., "Rechargeable Lithium Cells with High Energy Density Transition Metal Compound Cathodes – Characterization in AA-Size Cells," **CARDIVNSWC-TR-95/034**, Apr 1996.
3. Lin H.P. W. and Burgess, K., "Synthesis of Charged  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) for Primary and Secondary Batteries," U. S. Patent No. 5,667,660, Sept 16, 1997.
4. Linden, D., Chapter 14, "Lithium Cells," in **Handbook of Batteries**, Second Edition, Linden, D., Ed., McGraw-Hill, New York, 1995, p. 14-1, especially Figure 14.27, pp. 14.36, 14.37.
5. **Designer's Casebook**, Honeywell Power Sources Center, 1985.

**Appendix A**  
**HWAM Drawing Package**



**H-WAM Battery  
Device No. G3169A1  
Drawing Package  
22 February 1996**

## H-WAM DRAWING LIST

Drawing Package Requirements:

Drawing	Drawing Number	Used On/Next Assy
Battery Assembly	72007340 ✕	-
Battery Housing Assembly	72007341	72007340
Battery Housing Blank	72007342	72007341
Pressurizer	72007346	72007340
Bulkhead Assembly	72007347	72007340
Reservoir Housing	72007348	72007347
Insulator, Intra-Cell	72007349	72007340
Cell Case Assembly	72007350	72007340
Cell Case/Headers Assembly	72007351	72007350
Cell Case	72007352	72007351
Cell Case Cover	72007353	72007350
Cathode Separator Assembly	72007354	72007350
Anode Separator Assembly, Single-Sided	72007355	72007350
Anode Separator Assembly, Double-Sided	72007356	72007350
Anode Assembly, Single-Sided	72007357	72007355
Anode Assembly, Double-Sided	72007358	72007356
Cathode Assembly	72007359	72007354
Anode, Lithium Foil	72007360	72007357, 58
Cathode Current Collector	72007361	72007359
Anode Current Collector	72007362	72007357, 58
Header Assembly, Positive	72007363	72007351
Header, Positive	72007364	72007363
Tube, Fill	72007365	72007363
Eyelet, GTM	72007366	72007375
Spring, Compression	72007367	72007340
Header Assembly, Negative	72007368	72007351
Header, Negative	72007369	72007368
Electrolyte Diaphragm, Inlet	72007370	72007347
Electrolyte Diaphragm, Outlet	72007371	72007347
Vent, Cell Case	72007372	72007375
Battery Housing Vent	72007373	72007341
Tubing, Activation	72007374	72007340
Cell Case Vent/GTM Eyelet Assembly	72007375	72007363, 68
Bulkhead	72007376	72007347
Cathode Lead Assembly	72007378 ✕	7200xxxx
Anode Lead Assembly	72007379 ✕	7200xxxx
Ball	72007975	72007347
Lead Routing Assembly	720073xx ✕	7200xxxx
Pin Connectors (Outside Housing)	720073xx ✕	72007341

Spec Control Drawings:

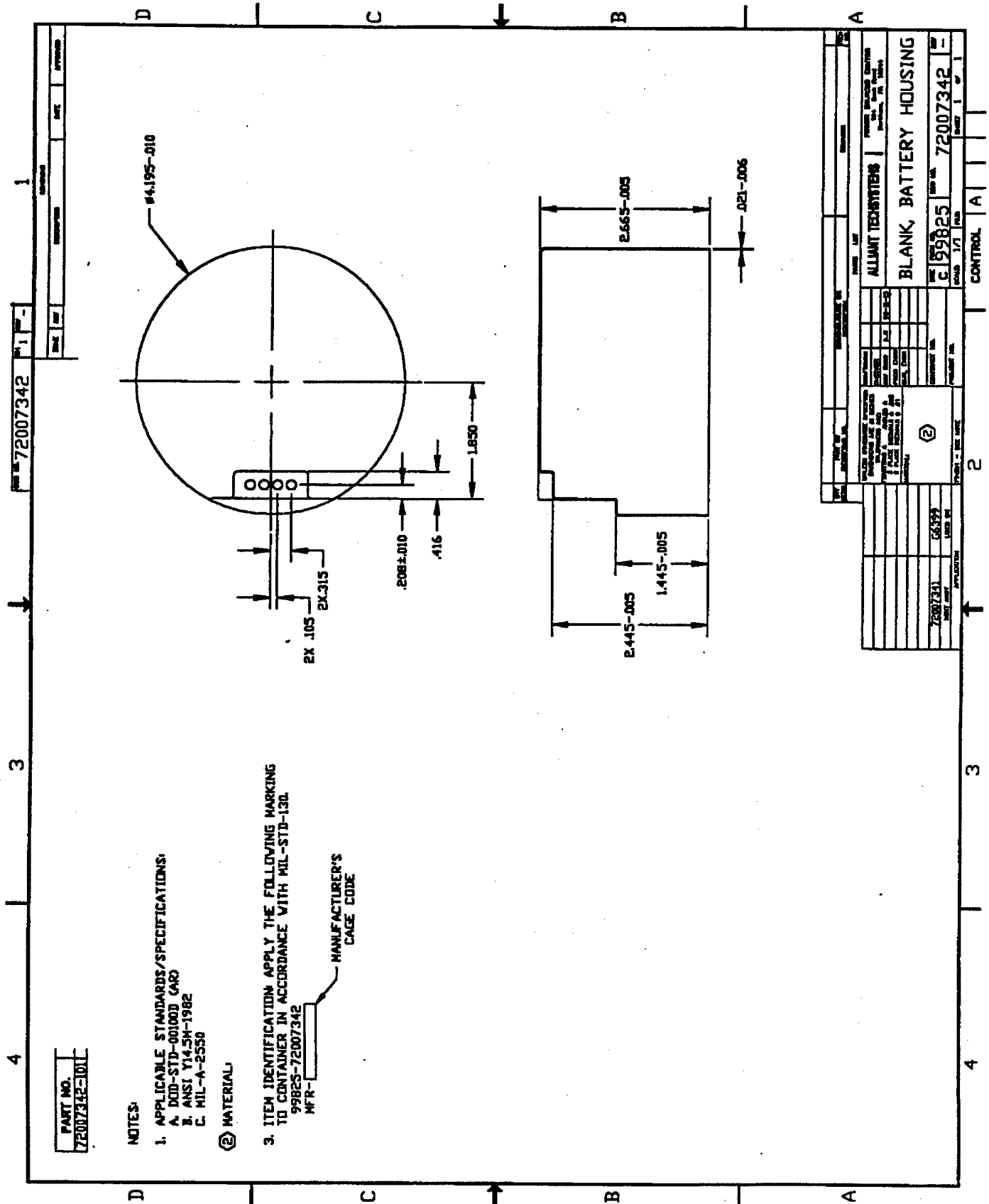
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Flame Arrestor Material	7200xxxx ✕	7200xxxx
Cathode Process Spec.	7200xxxx ✕	7200xxxx
Tefzel (ETFE)	7200xxxx ✕	72007351

2/15/96

HWDWGLST



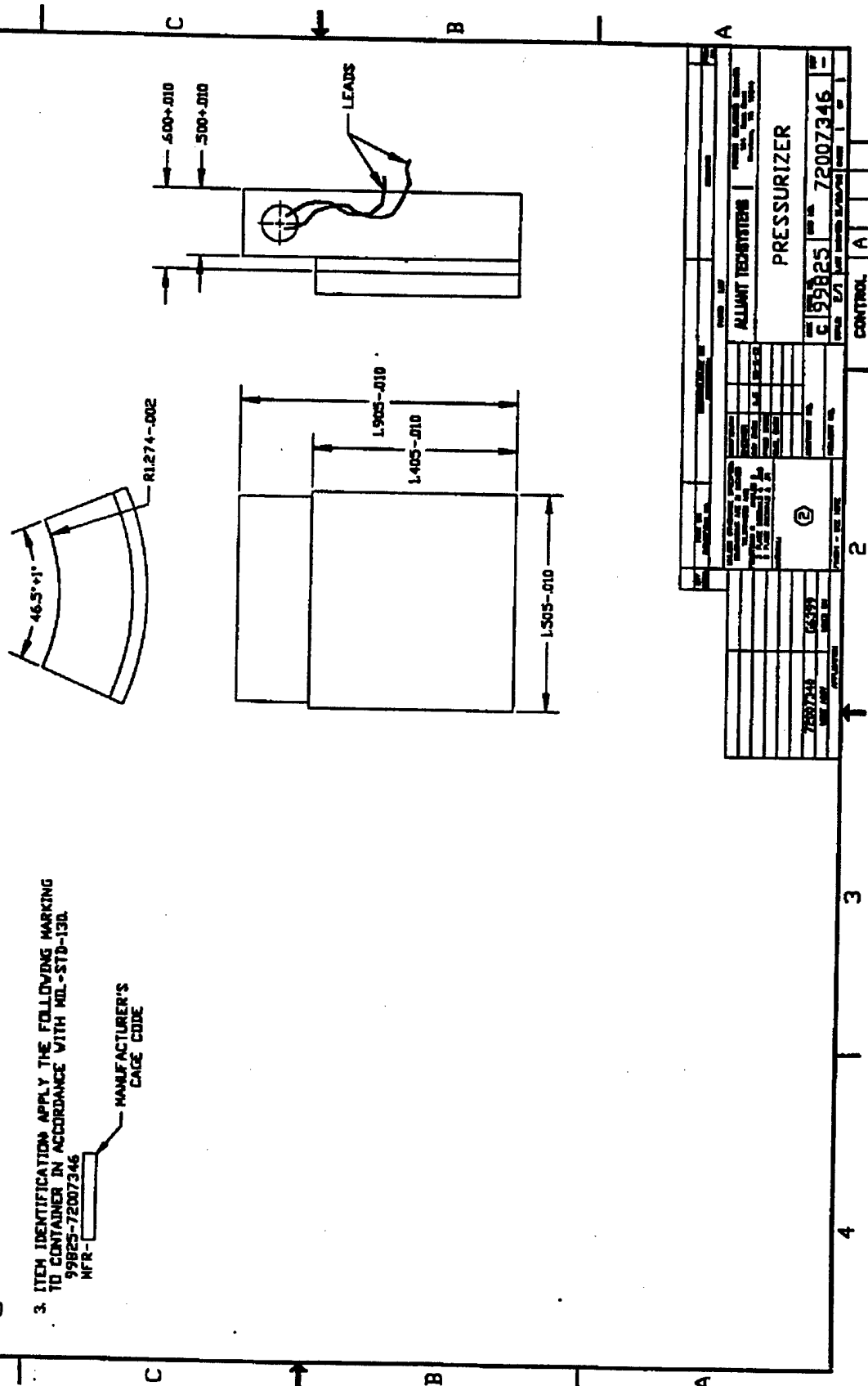


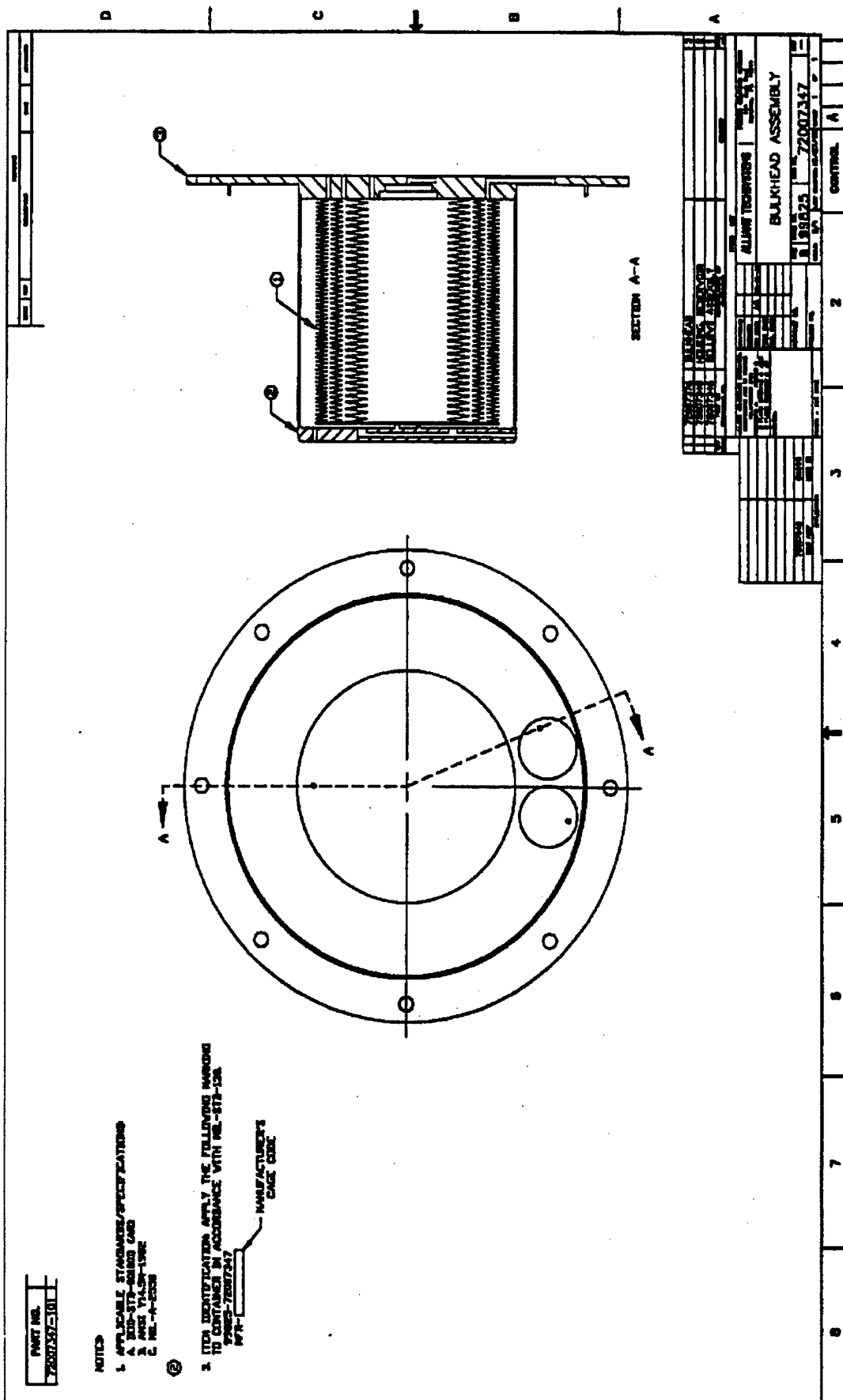


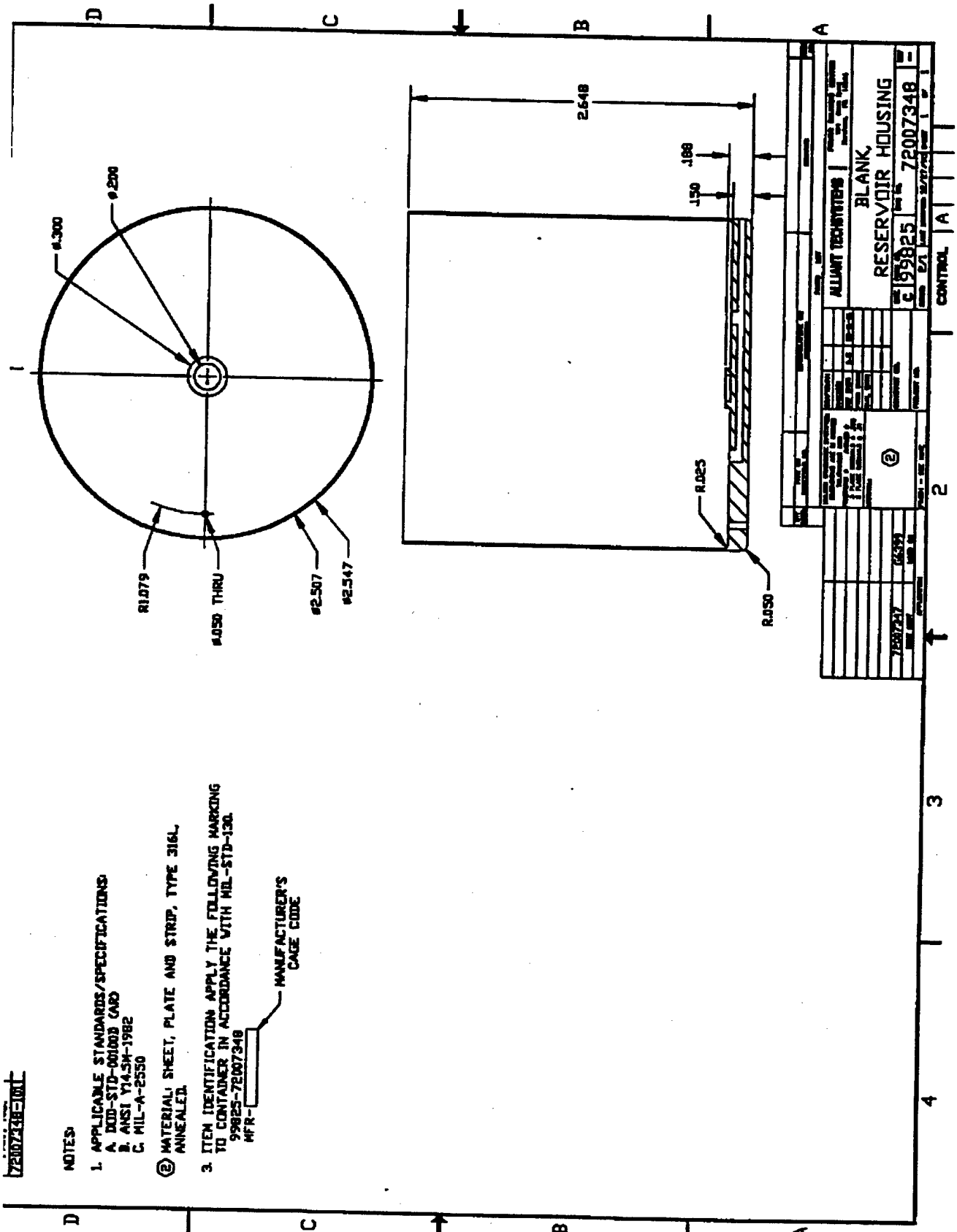
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C. MIL-A-2358

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99825-72007346  
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**MANUFACTURER'S  
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PART NO.  
72007349-101

## NOTES

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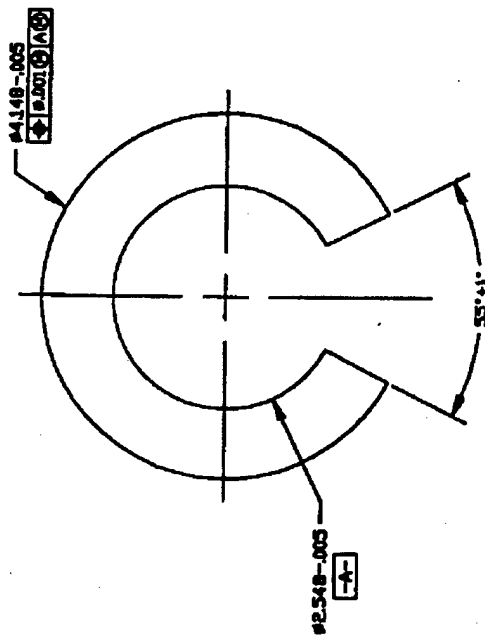
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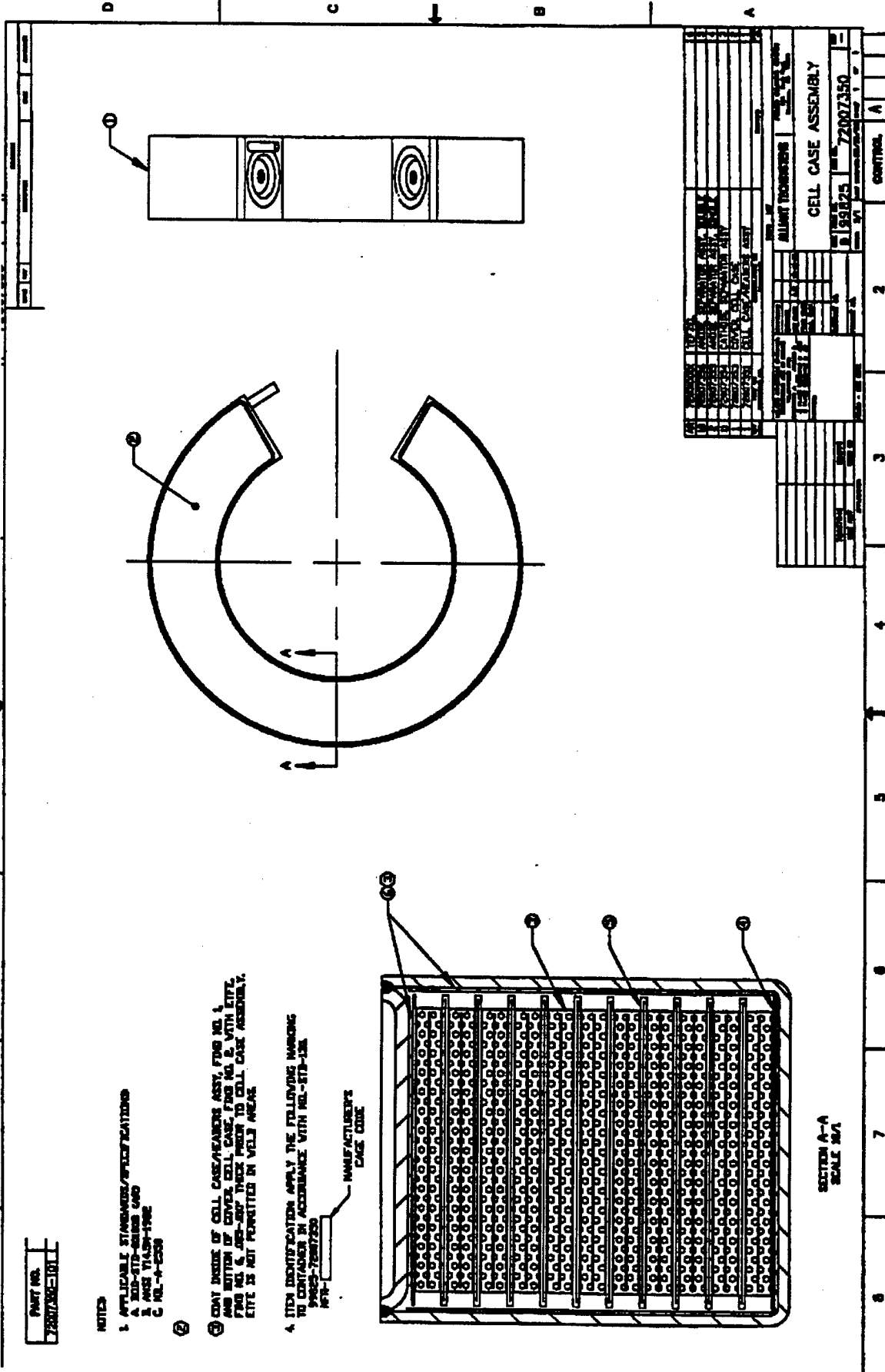
C. MIL-A-2550

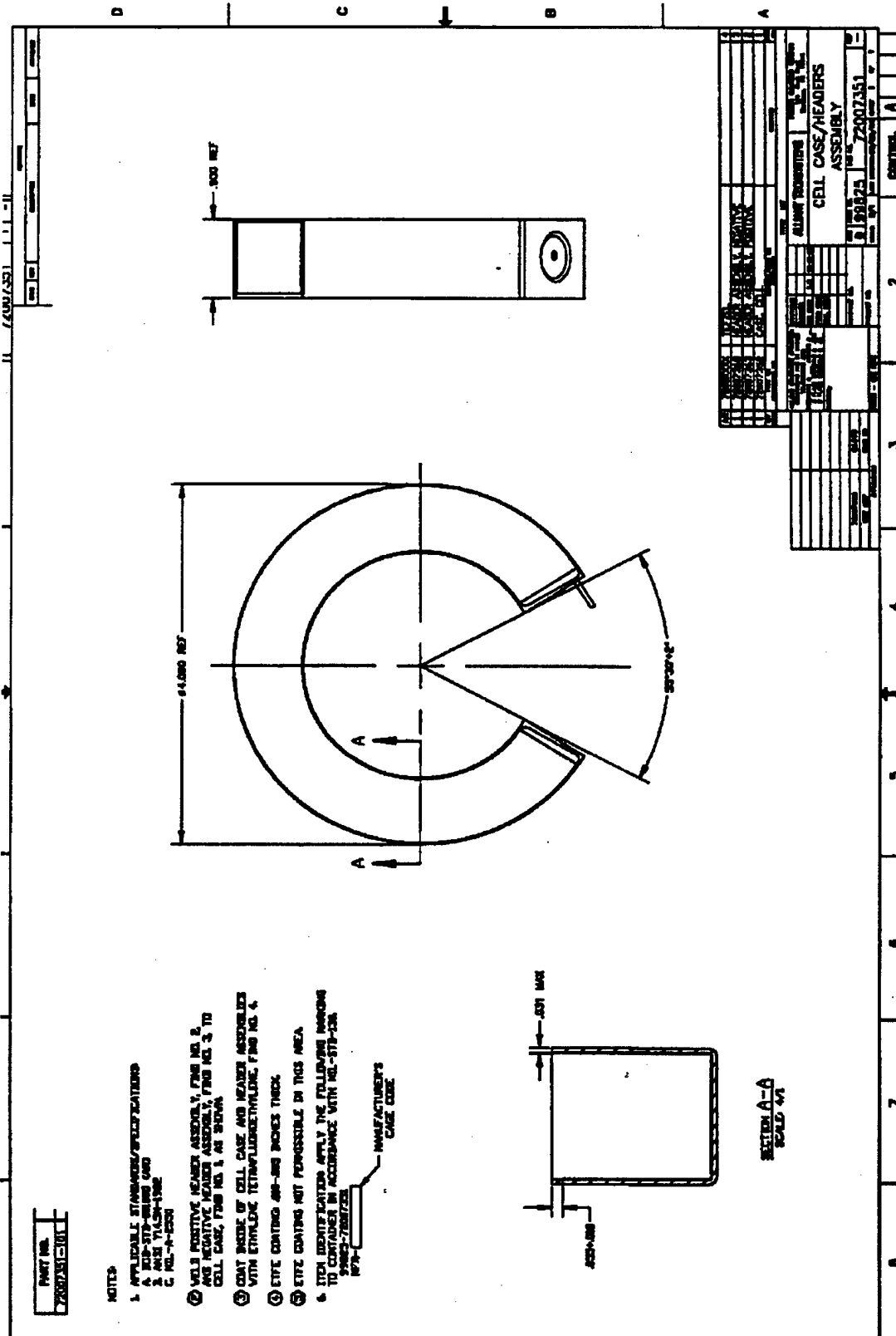
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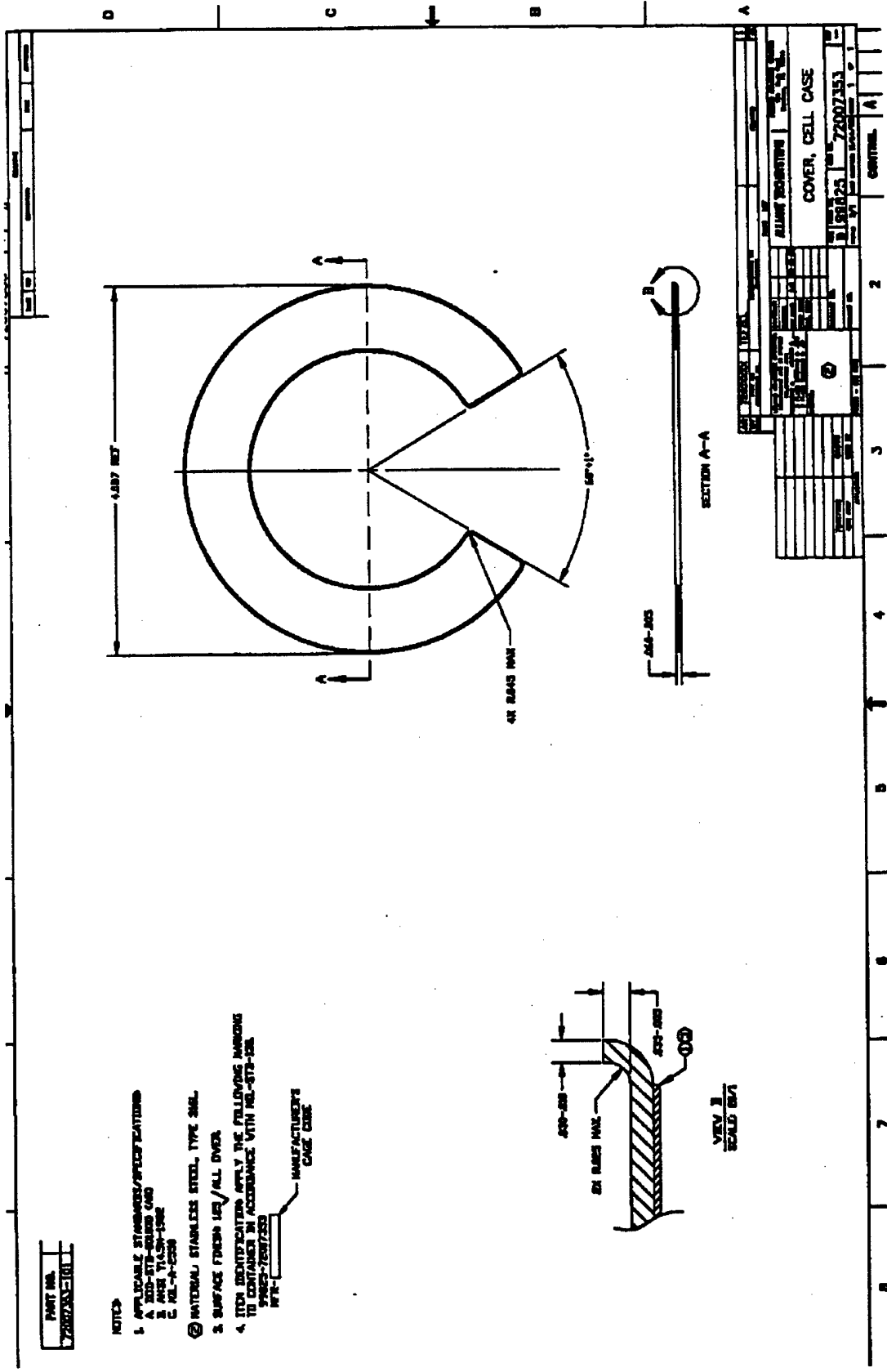
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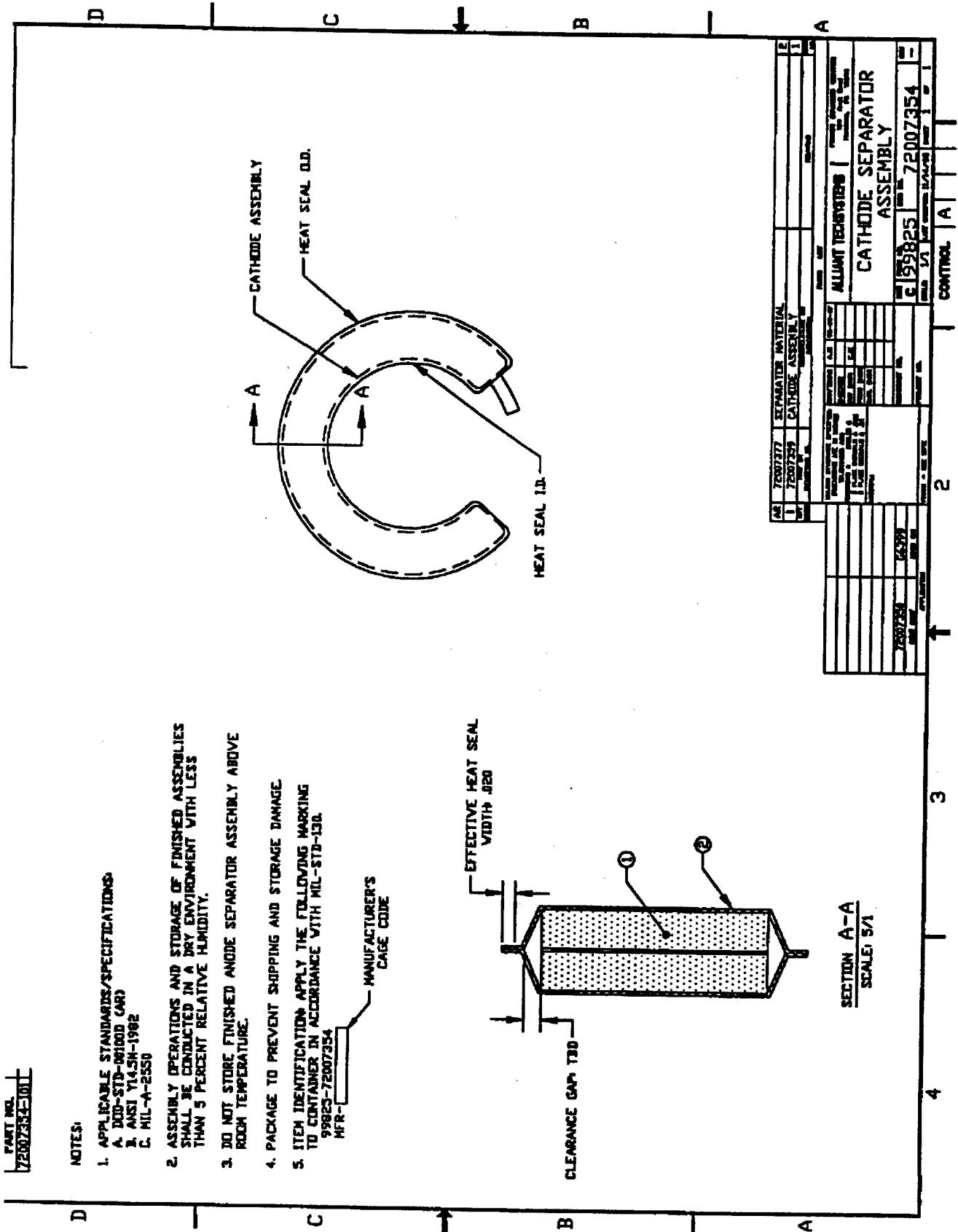










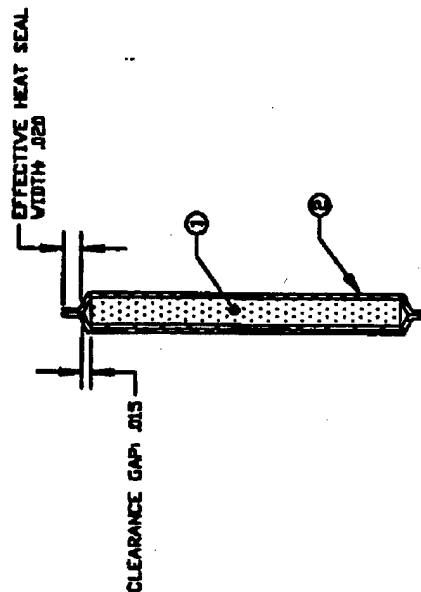


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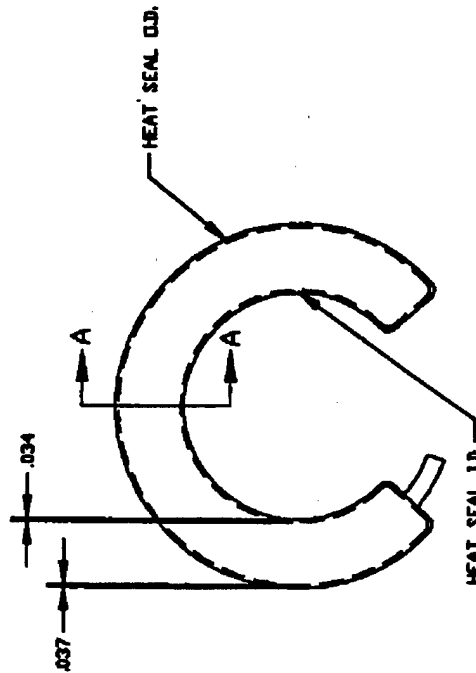
PART NO.  
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NOTES:

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2. ASSEMBLY OPERATIONS AND STORAGE OF FINISHED ASSEMBLIES SHALL BE CONDUCTED IN A DRY ENVIRONMENT WITH LESS THAN 5 PERCENT RELATIVE HUMIDITY.
3. DO NOT STORE FINISHED ANODE SEPARATOR ASSEMBLY ABOVE ROOM TEMPERATURE.
4. PACKAGE TO PREVENT SHIPPING AND STORAGE DAMAGE
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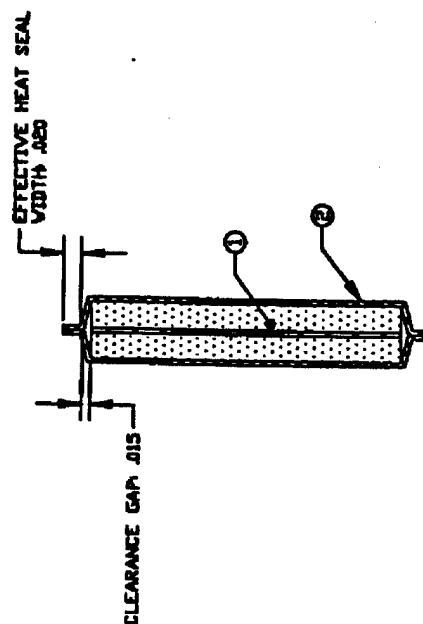
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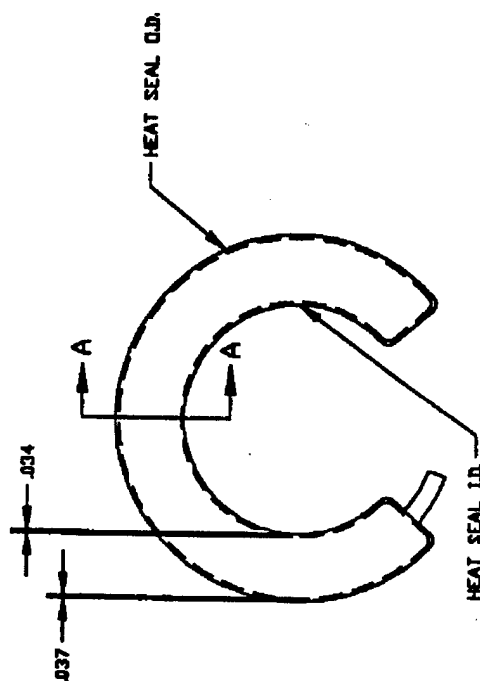
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72007355		ANODE SEPARATOR ASSEMBLY, SINGLE-SIDED		-93	
72007355		ANODE SEPARATOR ASSEMBLY, SINGLE-SIDED		-94	
72007355		ANODE SEPARATOR ASSEMBLY, SINGLE-SIDED		-95	
72007355		ANODE SEPARATOR ASSEMBLY, SINGLE-SIDED		-96	
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72007355		ANODE SEPARATOR ASSEMBLY, SINGLE-SIDED		-99	
72007355		ANODE SEPARATOR ASSEMBLY, SINGLE-SIDED		-100	

1. APPLICABLE STANDARDS/SPECIFICATIONS:
  - A. DDD-STD-001000 (AR)
  - B. ANSI Y14.5M-1982
  - C. MIL-A-2550
2. ASSEMBLY OPERATIONS AND STORAGE OF FINISHED ASSEMBLIES SHALL BE CONDUCTED IN A DRY ENVIRONMENT WITH LESS THAN 5 PERCENT RELATIVE HUMIDITY.
3. DO NOT STORE FINISHED AND/DE SEPARATOR ASSEMBLY ABOVE ROOM TEMPERATURE.
4. PACKAGE TO PREVENT SHIPPING AND STORAGE DAMAGE.
5. ITEM IDENTIFICATION: APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.  
99025-72007356

MANUFACTURER'S CAGE CODE



**SECTION A-A**  
**SCALE: 5/1**

[illegible]

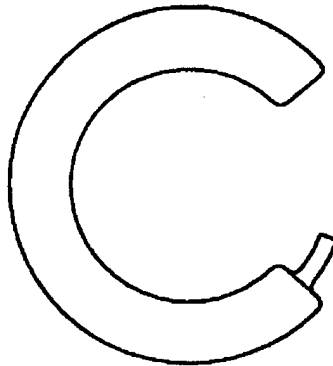
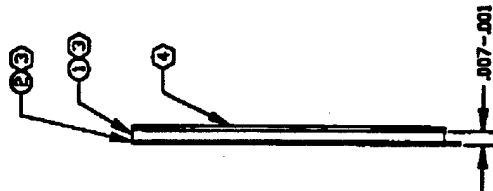
CONTROL	A
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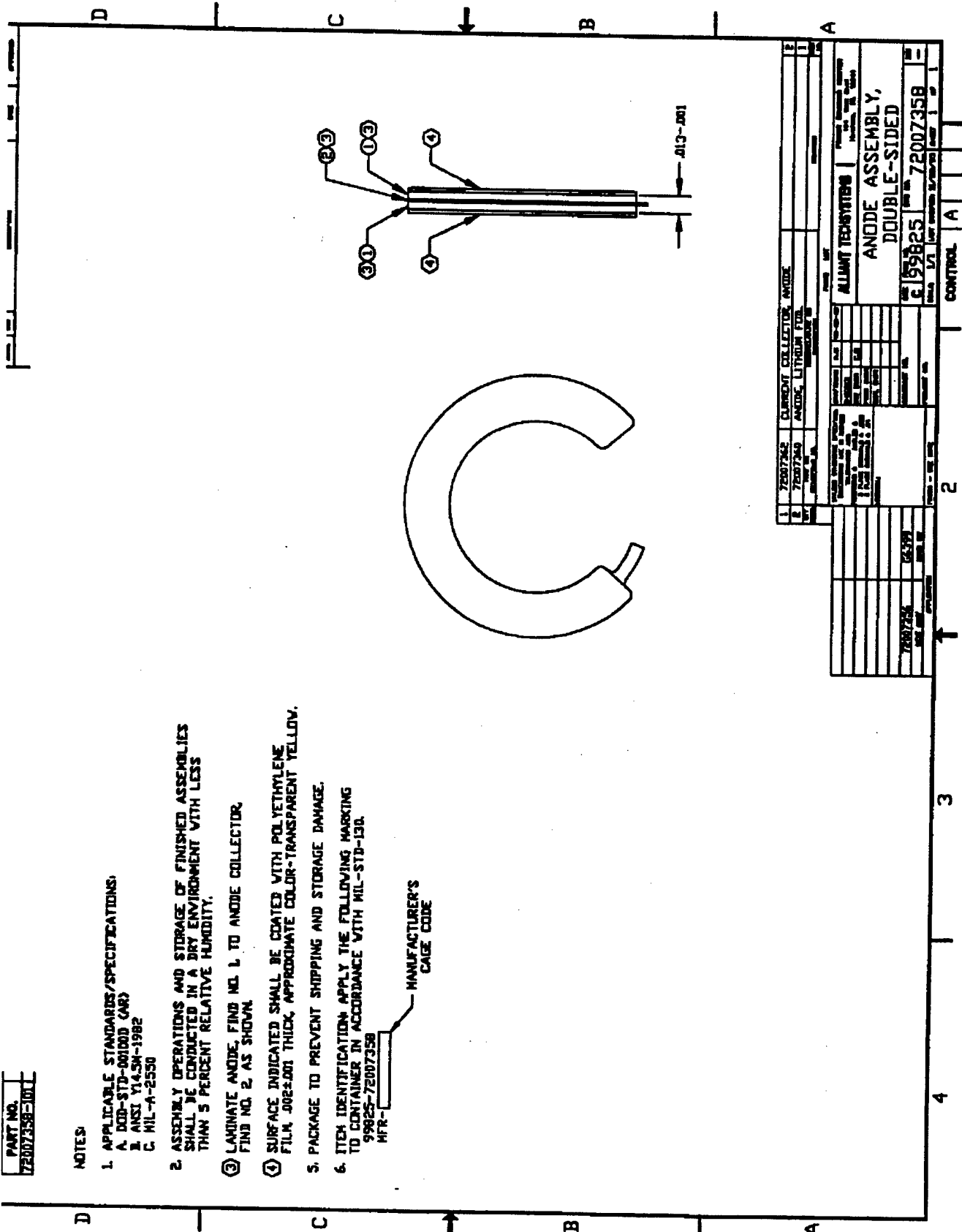
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A. DOD-STD-00100D (AR)  
B. ANSI Y14.5M-1982  
C. MIL-A-2550

2. ASSEMBLY OPERATIONS AND STORAGE OF FINISHED ASSEMBLIES SHALL BE CONDUCTED IN A DRY ENVIRONMENT WITH LESS THAN 5 PERCENT RELATIVE HUMIDITY.
- ③ LAMINATE ANODE, FIND NO. 1, TO ANODE COLLECTOR, FIND NO. 2, AS SHOWN.
- ④ SURFACE INDICATED SHALL BE COATED WITH POLYETHYLENE FILM, .002-.003 THICK, APPROXIMATE COLOR-TRANSPARENT YELLOW.
5. PACKAGE TO PREVENT SHIPPING AND STORAGE DAMAGE.
6. ITEM IDENTIFICATION APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MOL-STD-136.

99825-72007357  
MFR- [ ]

**MANUFACTURER'S  
CAGE CODE**

[illegible]



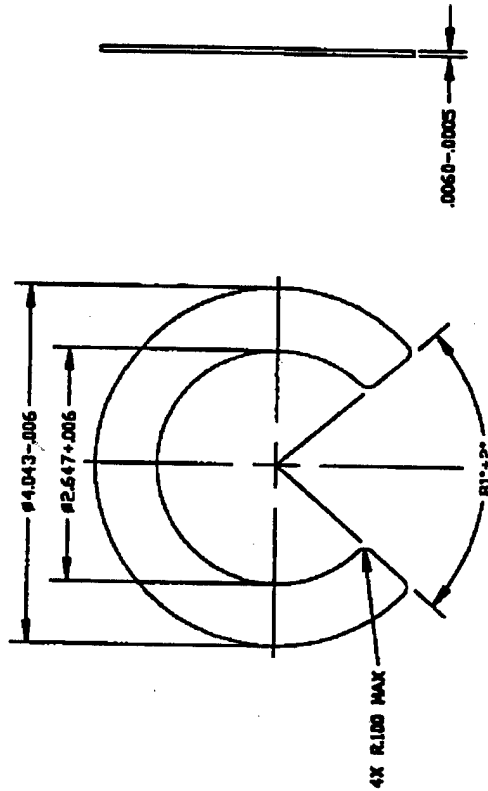


PART NO.  
72007360-101

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS:  
A. DDD-STD-001000 (AND)  
B. ANSI Y14.5M-1982  
C. MIL-A-2550
2. MATERIAL: LITHIUM, MIL-L-48772, GRADE 3.
3. PACKAGE TO PREVENT SHIPPING AND STORAGE DAMAGE.
4. ITEM IDENTIFICATION: APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.  
99825-72007360  
NFR-

MANUFACTURER'S  
CAGE CODE



ALLIANT TECHNOLOGIES		ANODE, LITHIUM FOIL	
Q	99825	72007360	1
CONTROL		A	



### 1. APPLICABLE STANDARDS/SPECIFICATIONS:

- A. DDD-STD-001000 (AR)  
B. ANSI Y14.5M-1982  
C. MIL-A-2550

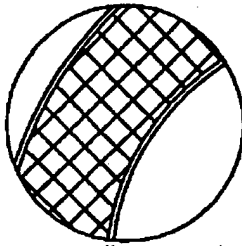
② MATERIAL: STAINLESS STEEL TYPE 316L

**3. PACKAGE TO PREVENT SHIPPING AND STORAGE DAMAGE.**

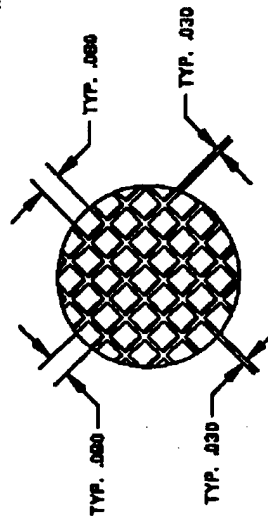
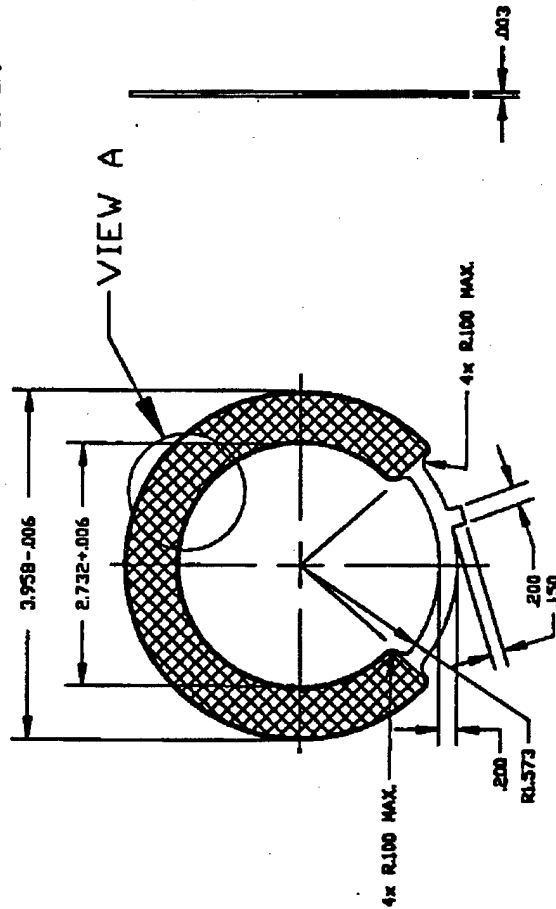
4. ITEM IDENTIFICATION: APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.

95825-7207361

**MANUFACTURER'S  
CAGE CODE**

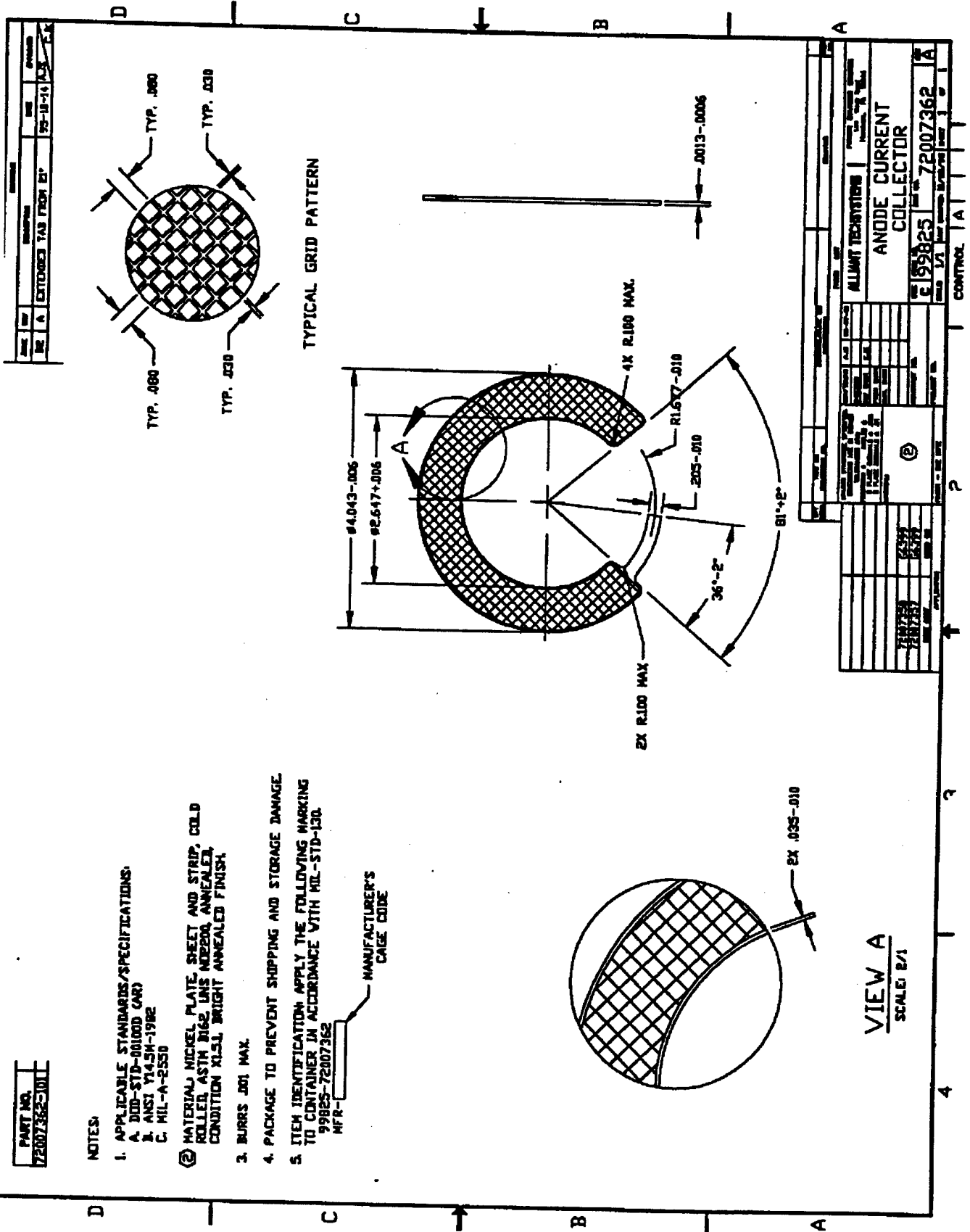


**VIEW A**  
**SCALE: 2x**



## GRID PATTERN

[illegible]



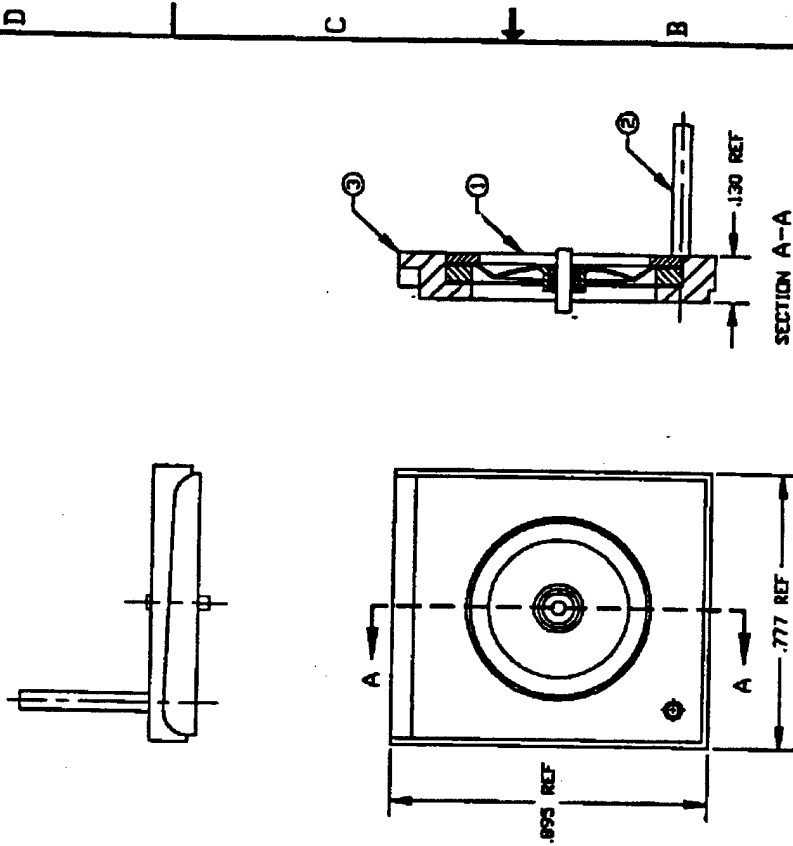
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- A. DOD-STD-00100D CARO  
B. ANSI Y14.5M-1982  
C. MIL-A-2550

3. ITEM IDENTIFICATION: APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.

99825-72007363  
MFR-

**MANUFACTURER'S  
CAGE CODE**



## SECTION A-A

[illegible]



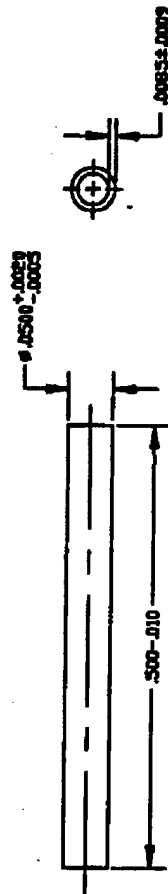
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B. ANSI Y14.3M-1982  
C. MIL-A-2550

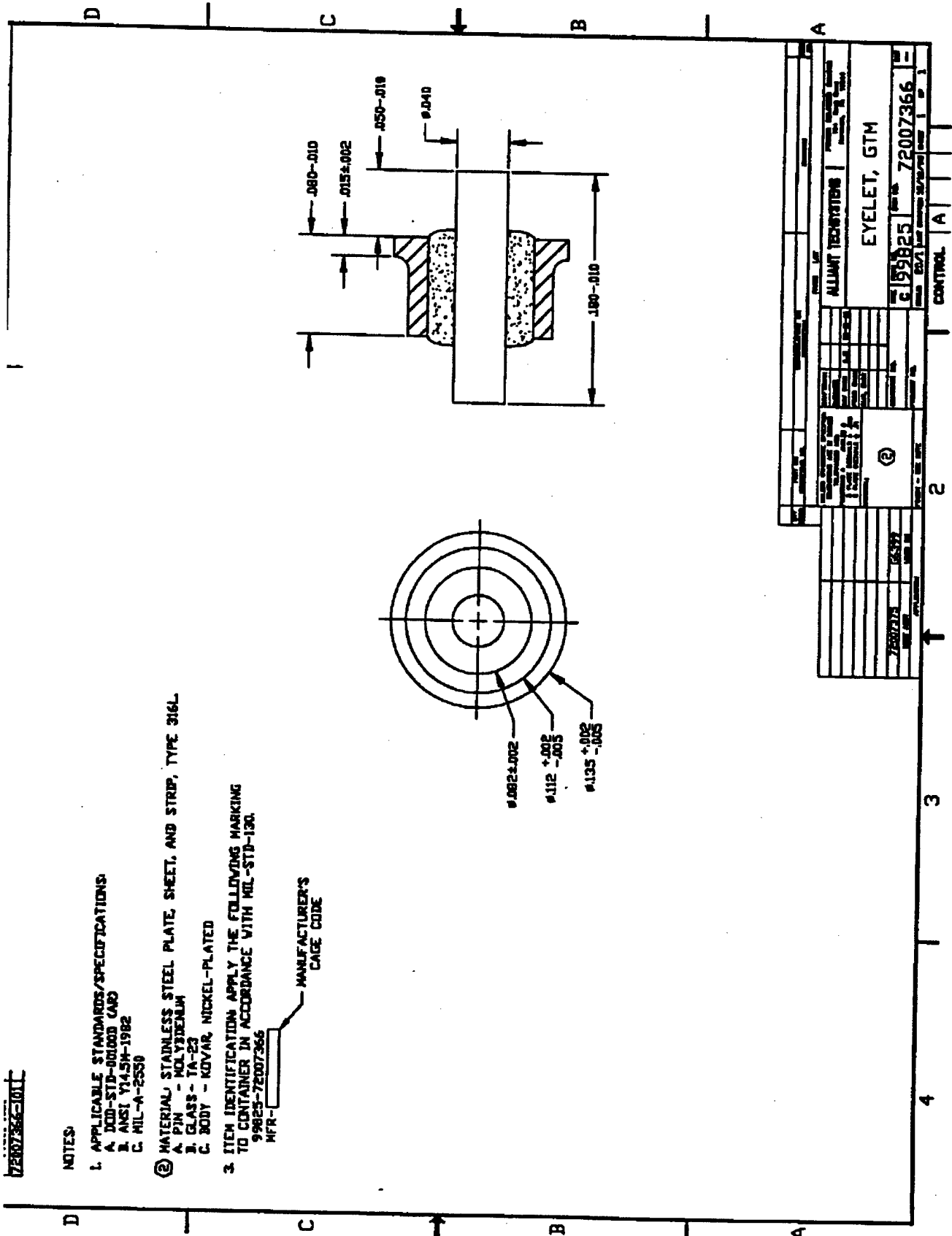
② MATERIAL: SEAMLESS STAINLESS STEEL TUBING  
ASTM A632, 304L

3. ITEM IDENTIFICATION: APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.

99023-72007365  
NFR- [ ]

**MANUFACTURER'S  
CASE CODE**

[illegible]





APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED
72007340	G6399	-	H-WAM	9/22/95	AJS

SUGGESTED SOURCE(S) OF SUPPLY				
PART NO.	VENDOR		VENDOR PART NUMBER	ITEM IDENTIFICATION
	ADDRESS	CAGE CODE		
72007367	LEE SPRING COMPANY 1462 62nd STREET BROOKLYN, NY 11219 FSCM NO. 84630	TBD	TBD	99825-72007367 MFR-LC-021AB-3MW

## SPECIFICATION CONTROL DRAWING

REV STATUS OF SHEETS	REV	-	-	-											
	SHEET	1	2	3											

CONTRACT NUMBER		PART NO. 72007367-101		
COMPUTER GENERATED	DRAWN BY AJS	ALLIANT TECHSYSTEMS INC., POWER SOURCES CENTER 104 Rock Road, Horsham, Pennsylvania 19044		
SYSTEM PPT WINDOWS	DATE 95-09-22	<h3>SPRING, COMPRESSION</h3>		
	CHECKER			
SOFTWARE REVISION 4.0	ENGINEER AJS			
	MATL ENGR			
DISK NO.	QUAL ENGR	SIZE A	CAGE CODE 99825	DWG NO. 72007367
FILENAME	PRODUCTION APPR			
	PROGRAM APPROVAL			
		SCALE: NONE		UNIT WT
				SHEET 1 OF 3

PROJ

END ITEM

CONTROL

**1.0 REQUIREMENTS:****1.1 MATERIAL: STEEL WIRE, MUSIC SPRING QUALITY, ASTM A228.****1.2 SPECIFICATIONS:**

	<u>REQUIREMENTS</u>
1.2.1 MUSIC WIRE DIAMETER	.021 +/- .001
1.2.2 OUTSIDE DIAMETER	.148 +/- .003
1.2.3 APPROX. LOAD AT SOLID HEIGHT	4.0 LBS
1.2.4 FREE LENGTH	.374 NOM.
1.2.5 SPRING RATE LB/IN	20.0 +/- .2
1.2.6 SOLID HEIGHT	.185 NOM.
1.2.7 ZINC PLATE, ASTM B633	.0002 THK.
1.2.8 TYPE OF ENDS	SQUARE NOT GROUND
1.2.9 DIRECTION OF WIND	OPTIONAL

**2.0 QUALITY ASSURANCE PROVISIONS:**

- 2.1 RESPONSIBILITY FOR INSPECTION:** UNLESS OTHERWISE SPECIFIED IN THE CONTRACT OR PURCHASE ORDER, THE CONTRACTOR IS RESPONSIBLE FOR THE PERFORMANCE OF THE INSPECTION REQUIREMENTS. THE CONTRACTOR MAY USE HIS OWN OR ANY OTHER FACILITIES APPROVED BY THE GOVERNMENT FOR THE PERFORMANCE OF INSPECTION REQUIREMENTS SPECIFIED HEREIN. THE GOVERNMENT RESERVES THE RIGHT TO PERFORM ANY OF THE INSPECTIONS SET FORTH IN THE DRAWING WHERE SUCH INSPECTIONS ARE DEEMED NECESSARY TO ASSURE THAT SUPPLIES CONFORM TO PRESCRIBED REQUIREMENTS.
- 2.2 INSPECTION CONDITIONS:** UNLESS OTHERWISE SPECIFIED, THE INSPECTION SHALL BE CONDUCTED AT ROOM AMBIENT TEMPERATURE.
- 2.3 QUALITY CONFORMANCE:** UNLESS OTHERWISE SPECIFIED AND WHEN APPLICABLE, THE QUALITY CONFORMANCE TEST USED IN DETERMINING THE ACCEPTABILITY OF PRODUCTS SHALL BE IN ACCORDANCE WITH THE CONTRACTOR'S INSPECTION PLAN. INSPECTION OF EACH LOT OF MATERIAL SUBMITTED FOR ACCEPTANCE SHALL BE PERFORMED BY THE CONTRACTOR. CERTIFIED TEST DATA WITH ACCOMPANYING TEST RESULTS ARE ACCEPTABLE.

SIZE <b>A</b>	CAGE CODE <b>99825</b>	DWG. NO. <b>72007367</b>
SCALE: NONE UNIT WT		SHEET 2 OF 3
PROJ	END ITEM	CONTROL -



843

DWG NO. 72007367

**3.0 MARKING:**

**3.1 RUBBER STAMP OF STENCIL "99825-72007373" IN ACCORDANCE WITH MIL-STD-130, IN .125" HIGH CHARACTERS ON ITEM CONTAINER, USING BLACK STENCIL INK, TT-I-1795, TYPE II.**

**4.0 IDENTIFICATION OF THE SUGGESTED SOURCE(S) OF SUPPLY HEREON IS NOT TO BE CONSTRUED AS A GUARANTEE OF PRESENT OR CONTINUED AVAILABILITY AS A SOURCE OF SUPPLY FOR THE ITEM(S).**

SIZE	CAGE CODE	DWG. NO.
A	99825	72007367
SCALE: NONE	UNIT WT	SHEET 3 OF 3

PROJ

END ITEM

CONTROL

-

## NOTES

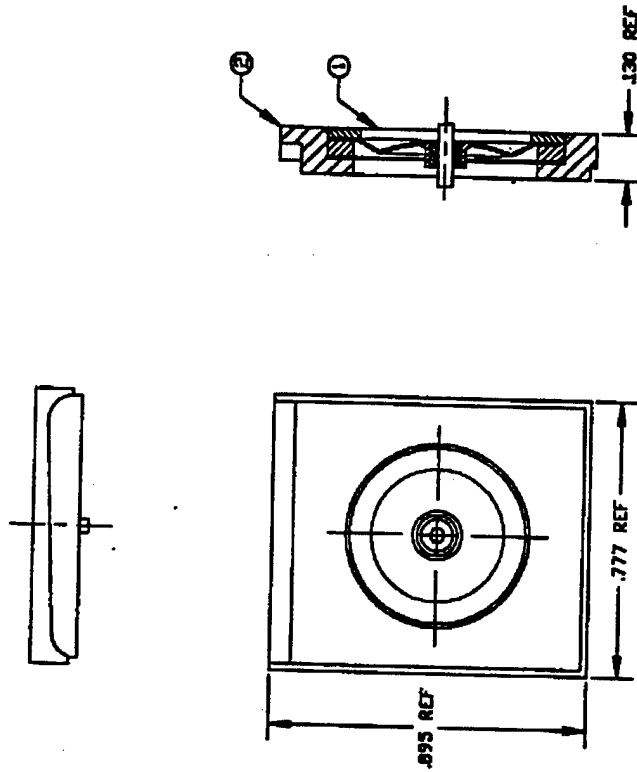
## NOTES

1. APPLICABLE STANDARDS/SPECIFICATIONS:  
A. DOD-STD-00100B (AR)  
B. ANSI Y14.5M-1982  
C. MIL-A-2550

3. ITEM IDENTIFICATION APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.  
99B25-72007368

720-757-7300  
MFR-

MANUFACTURER'S  
CAGE CODE

[illegible]

72007369-001

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS:  
 A. DOD-STD-061000 (CAR)  
 B. ANSI Y14.5M-1982  
 C. MIL-A-25350

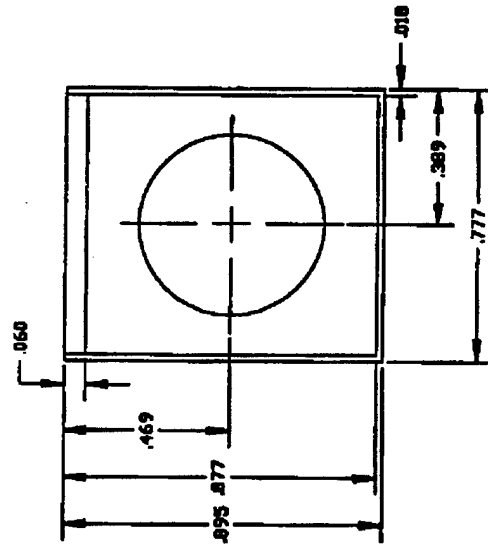
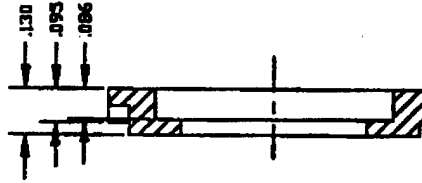
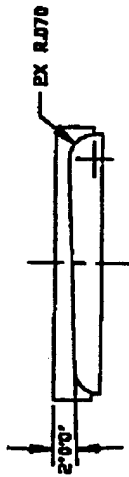
② MATERIAL: STAINLESS STEEL PLATE, SHEET, AND STRIP, TYPE 316L.

3. ITEM IDENTIFICATION APPLY THE FOLLOWING MARKING  
 TO CONTAINER IN ACCORDANCE WITH MIL-STD-130

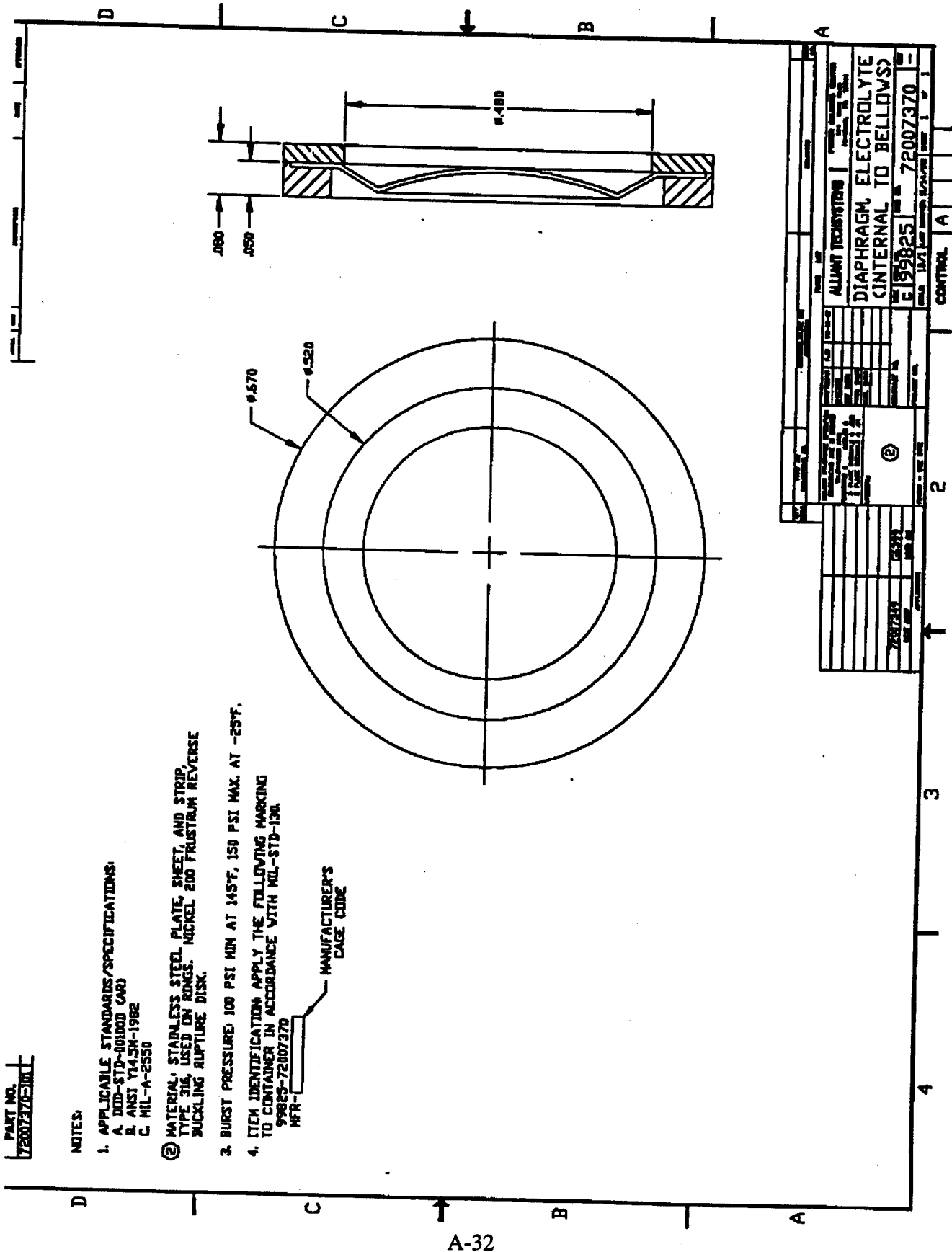
99825-72007369

HFR-

MANUFACTURER'S  
CAGE CODE



ALLIANT TECHNOLOGIES		HEADER, NEGATIVE	
C 199825		72007369	
CONTROL		A	



### L. APPLICABLE STANDARDS/SPECIFICATIONS:

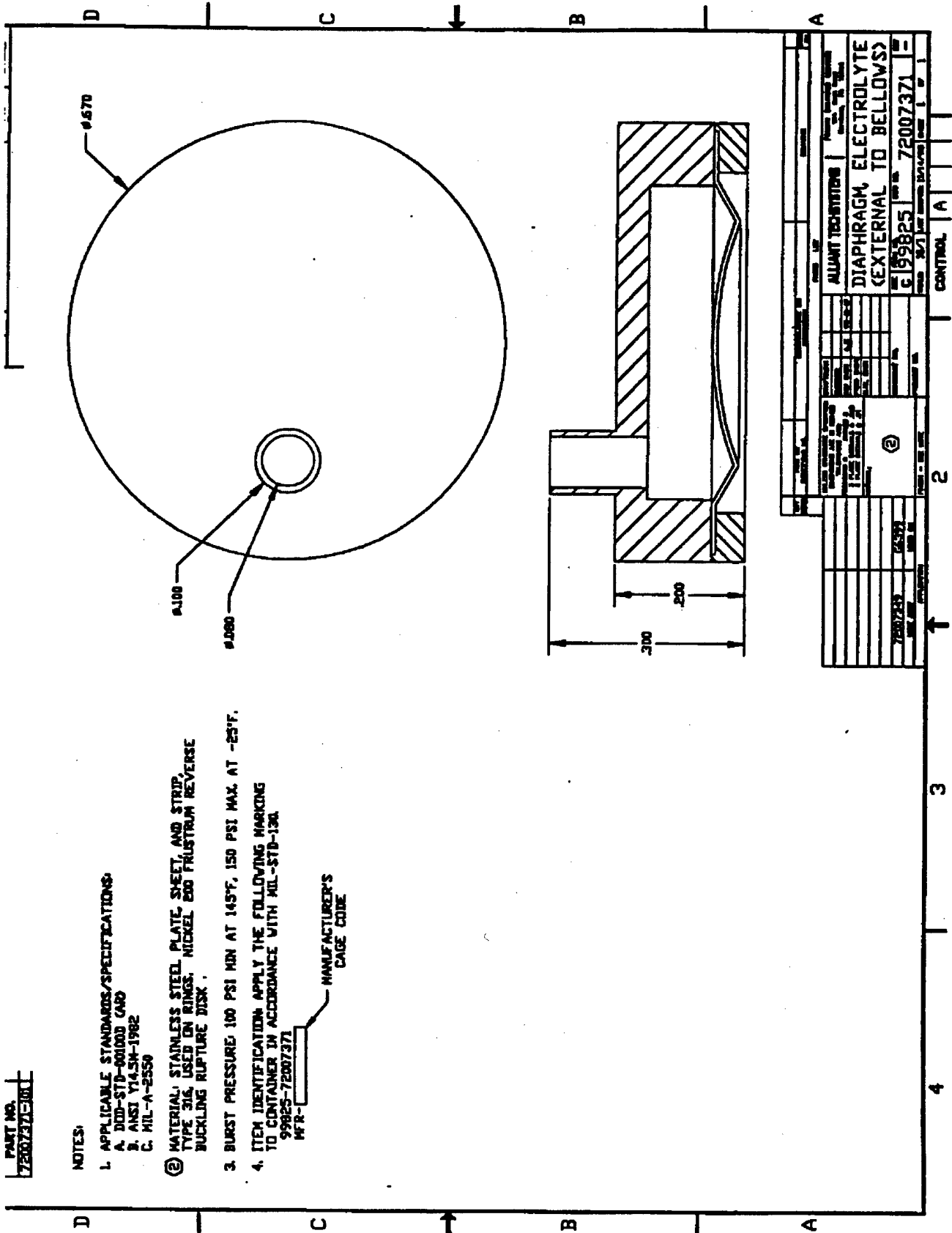
- A. DOD-STD-001000 (AR)  
B. ANSI Y14.5M-1982  
C. MIL-A-2550

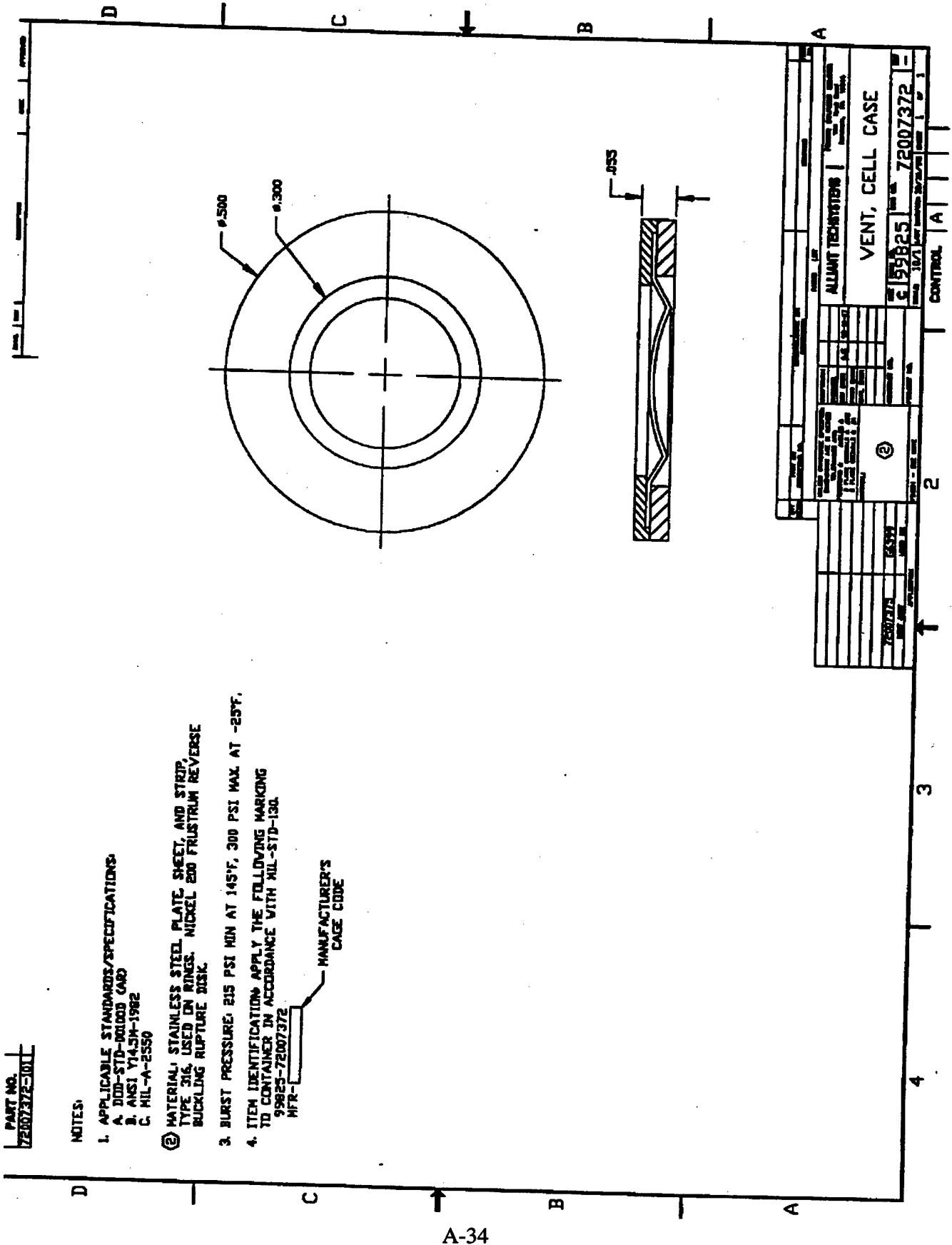
② MATERIAL: STAINLESS STEEL PLATE, SHEET, AND STRIP, TYPE 316, USED ON RINGS; NICKEL BOD FRUSTRUM REVERSE BUCKLING RUPTURE DISK.

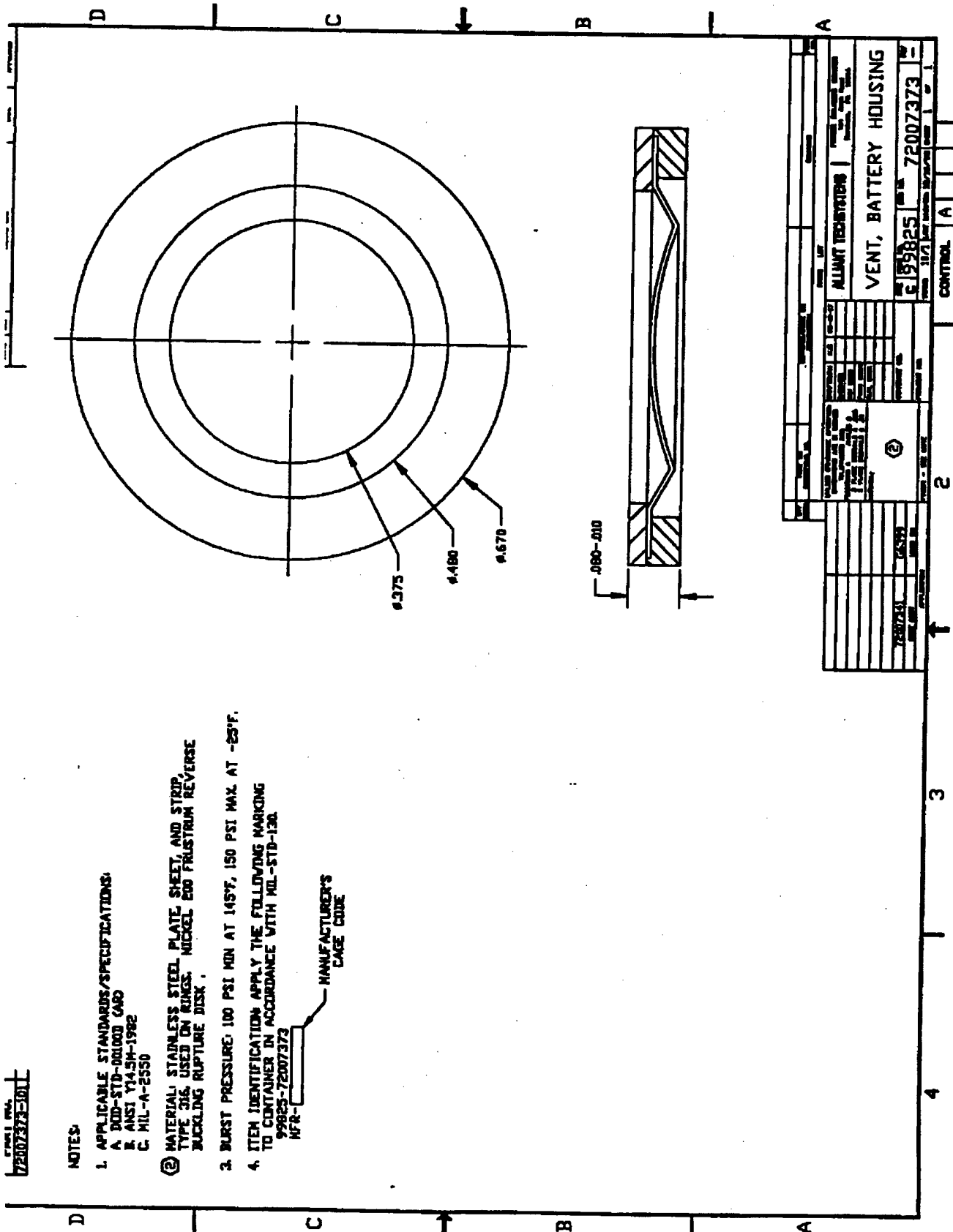
3. BURST PRESSURE: 100 PSI MIN AT 145°F, 150 PSI MAX AT -25°F.
4. ITEM IDENTIFICATION APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.

11-83M-1200737

**MANUFACTURER'S  
CAGE CODE**



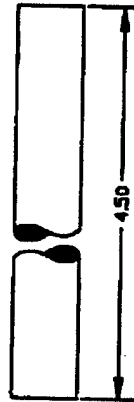
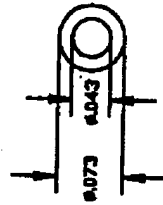




PART NO.  
72007374-001

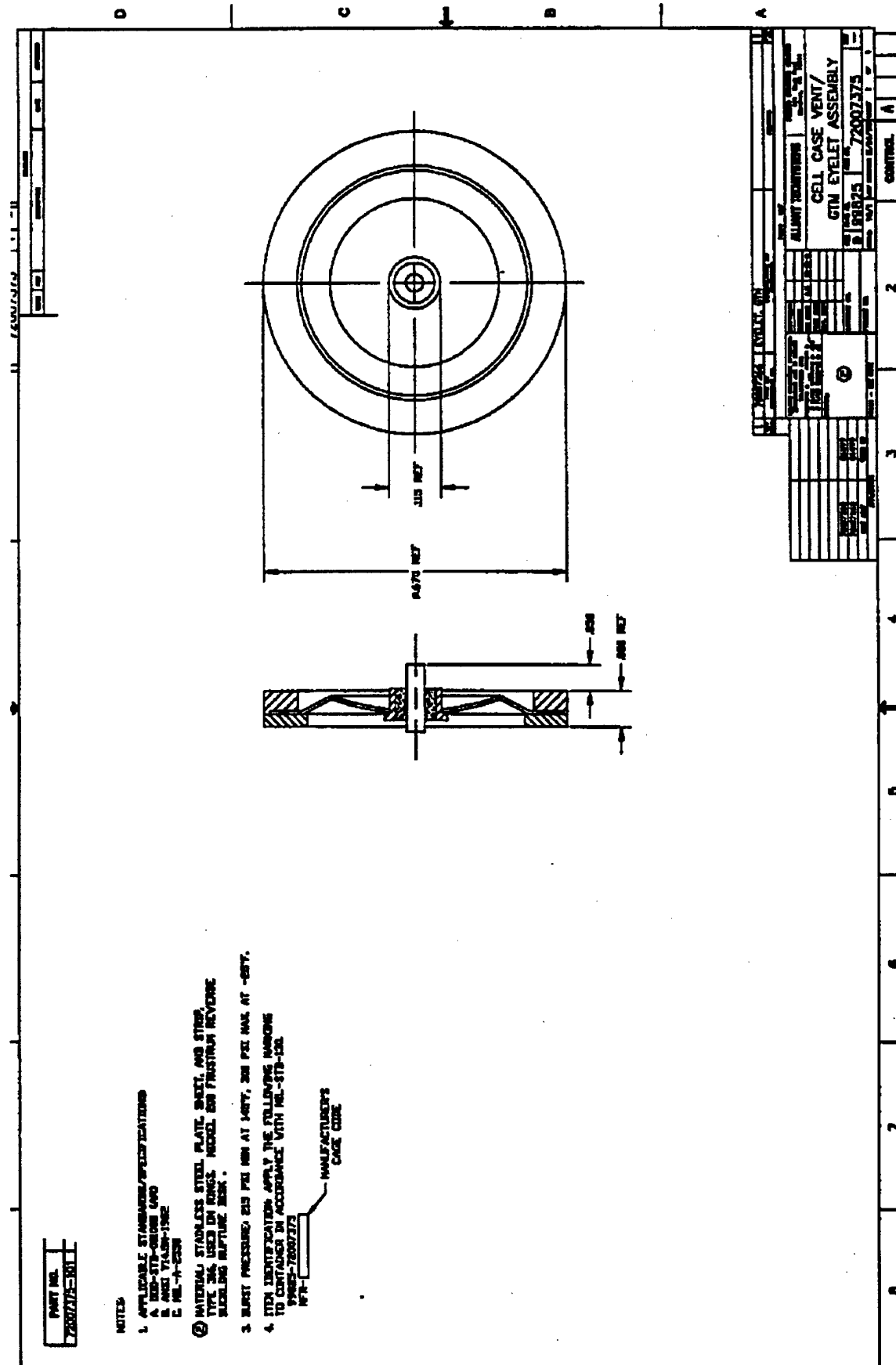
## NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS:  
 A. DDID-STD-001000 CARD  
 B. ANSI Y14.5M-1982  
 C. MIL-A-2550
2. MATERIAL: ETHYLENE TETRAFLUOROETHYLENE EXTRUSION TUBING IN ACCORDANCE WITH AMS 3532. PRIOR TO MAKING PIECE PARTS, HELIUM LEAK CHECK REEL STOCK MATERIAL IN ACCORDANCE WITH MIL-STD-882C METHOD 112. TEST CONDITION C, PROCEDURE 1, LEAK RATE NOT TO EXCEED 1 X 10<sup>-6</sup> ATM CC/SEC OF HELIUM.
3. ITEM IDENTIFICATION APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.  
 MFR-99825-72007374 MANUFACTURER'S CAGE CODE



PART NO.		72007374-001	
REV		1	
DATE		10/10/98	
BY		J. J. J.	
CHECKED BY		J. J. J.	
APPROVED BY		J. J. J.	
MATERIAL		ETHYLENE TETRAFLUOROETHYLENE EXTRUSION TUBING	
SPECIFICATION		MIL-STD-882C	
TEST METHOD		METHOD 112	
TEST CONDITION		CONDITION C	
PROCEDURE		PROCEDURE 1	
LEAK RATE		1 X 10 <sup>-6</sup> ATM CC/SEC OF HELIUM	
MFR		99825-72007374	
MANUFACTURER'S CAGE CODE		99825	
TUBING, ACTIVATION		72007374	
CONTROL		A	







72007975-1001

NOTES:

1. APPLICABLE STANDARDS/SPECIFICATIONS:

- A. DTD-STD-001000 CAD
- B. ANST Y14.5M-1982
- C. MIL-A-2550

2. REQUIREMENTS:

- A. MATERIAL: STAINLESS AND HEAT-RESISTING STEEL BARS AND SHAPES, ASTM A276
- B. CONFORMING TO THE CHEMICAL COMPOSITION OF UNS S44003 OR UNS S44004
- C. TOLERANCE FOR INDIVIDUAL BALLS:

- 1. ALLOWABLE BALL DIAMETER VARIATION:  $10 \times 10^{-4}$
- 2. ALLOWABLE DEVIATION FROM SPHERICAL FORM:  $10 \times 10^{-4}$
- 3. ALLOWABLE SURFACE ROUGHNESS (ARITHMETICAL AVERAGE):  $10 \times 10^{-4}$

D. TOLERANCE FOR LOTS OF BALLS:

- 1. ALLOWABLE LOT DIAMETER VARIATION:  $20 \times 10^{-4}$
- 2. BASIC DIAMETER TOLERANCE:  $\pm 100 \times 10^{-4}$
- 3. ALLOWABLE BALL GAGE DEVIATION:

- A. HIGH:  $\pm 50 \times 10^{-4}$
- B. LOW:  $-40 \times 10^{-4}$
- C. CONTAINER MARKING INCREMENT:  $10 \times 10^{-4}$
- D. MATERIAL DENSITY: 277 LBS/CUBIC INCH

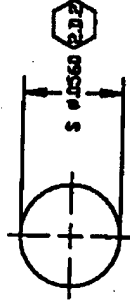
3. IDENTIFICATION OF THE "SUGGESTED SOURCES" OF SUPPLY HEREON IS NOT TO BE CONSIDERED AS A GUARANTEE OF PRESENT OR CONTINUED AVAILABILITY AS A SOURCE OF SUPPLY FOR THE ITEMS.

4. ITEM IDENTIFICATION APPLY THE FOLLOWING MARKING TO CONTAINER IN ACCORDANCE WITH MIL-STD-130.

99825-72007975

MFR-

MANUFACTURER'S  
CAGE CODE PART NO.



SUGGESTED SOURCE(S) OF SUPPLY			
PART NO.	ADDRESS	CAGE CODE	ITEM IDENTIFICATION
72007975	VINSTEED PRECISION BALL CORP. 12 ROCKWELL ST. PO BOX 679 VINSTEED, CT 06098-0679	27872	99825-72007975 MFR-

SPECIFICATION CONTROL DRAWING

ALLIANT TECHNOLOGIES		BALL	
72007975	99825	72007975	
CONTROL		A	

**Appendix B**

**U.S. Patent NO.: 5,667,660 Synthesis of Charged  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) for Primary and Secondary Batteries**



US005667660A

## United States Patent [19]

[11] Patent Number: 5,667,660

Lin et al.

[45] Date of Patent: Sep. 16, 1997

[54] SYNTHESIS OF CHARGED  $\text{Li}_x\text{COO}_2$  ( $0 < x < 1$ )  
FOR PRIMARY AND SECONDARY  
BATTERIES

[75] Inventors: Hsiu-Ping W. Lin, Princeton, N.J.;  
Kevin Burgess, Horsham, Pa.

[73] Assignee: Alliant Techsystems Inc., Hopkins,  
Minn.

[21] Appl. No.: 527,208

[22] Filed: Sep. 12, 1995

[51] Int. Cl.<sup>6</sup> ..... H01M 4/04

[52] U.S. Cl. .... 205/59; 429/218

[53] Field of Search ..... 205/59; 429/218;  
427/201; 126.6

[56] References Cited

## U.S. PATENT DOCUMENTS

4,497,726 2/1985 Brule et al. .... 252/182.1

4,804,596 2/1989 Ebner et al. .... 429/194  
4,818,647 4/1989 Plichta et al. .... 429/218  
5,110,696 5/1992 Shokoochi et al. .... 429/218  
5,296,319 3/1994 Bito et al. .... 429/218 X  
5,427,875 6/1995 Yamamoto et al. .... 429/218 X

## OTHER PUBLICATIONS

Gummow et al., "Characterization of  $\text{LT-Li}_x\text{Co}_{1-x}\text{Ni}_x\text{O}_2$   
Electrodes for Rechargeable Lithium Cells", J. Electrochem.  
Soc., vol. 140, No. 12, Dec. 1993, pp. 3365-3368.

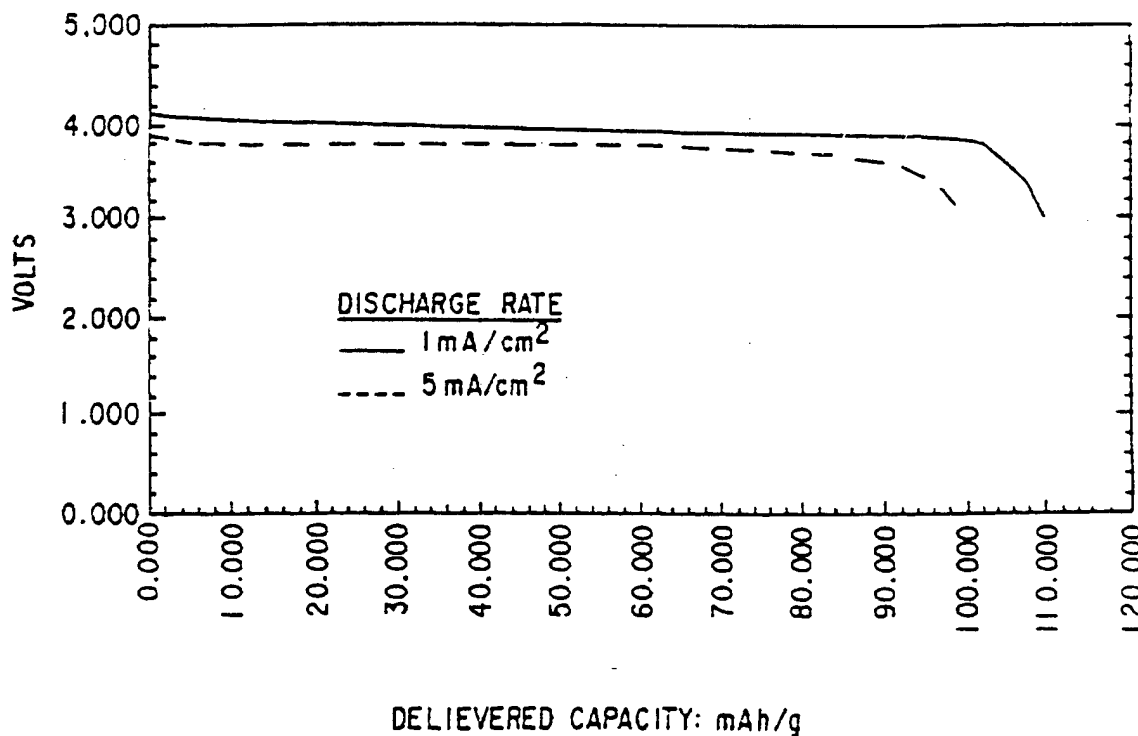
Primary Examiner—Stephen Kalafut

Attorney, Agent, or Firm—Haugen and Nikolai, P.A.

## [57] ABSTRACT

A method for producing stable pre-charged  $\text{Li}_x\text{CoO}_2$  as the  
cathode active metal in primary or secondary active metal  
non-aqueous cells and cells using such material are dis-  
closed.

13 Claims, 5 Drawing Sheets



U.S. Patent

Sep. 16, 1997

Sheet 1 of 5

5,667,660

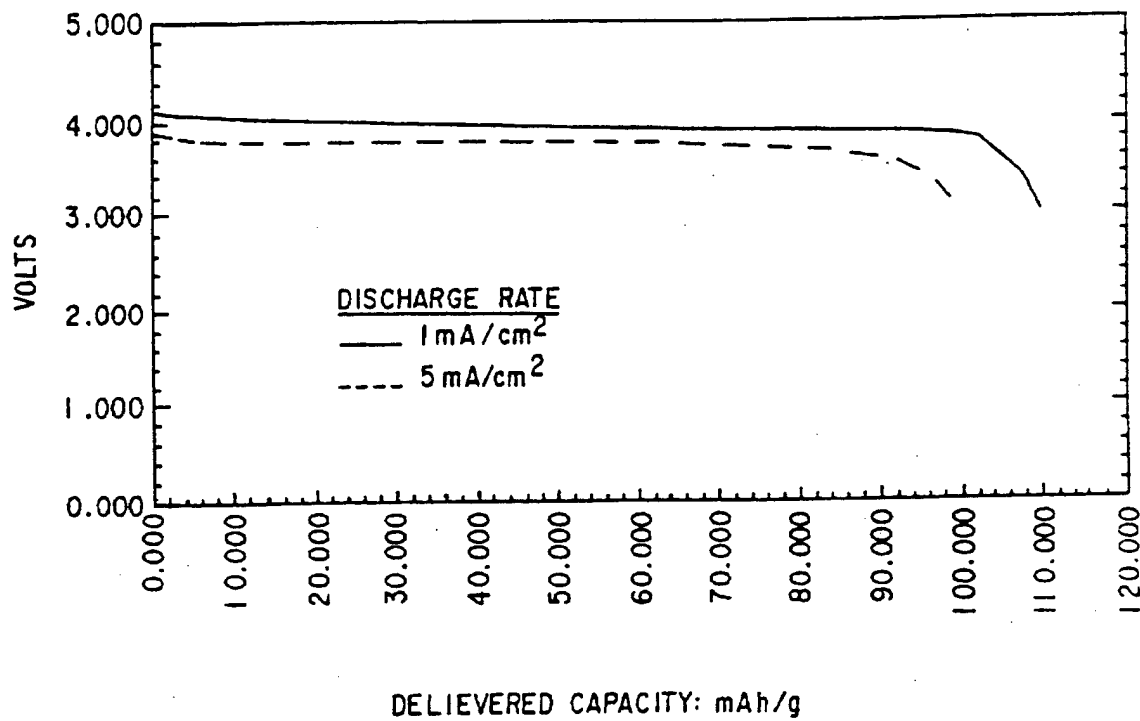


FIG. 1

U.S. Patent

Sep. 16, 1997

Sheet 2 of 5

5,667,660

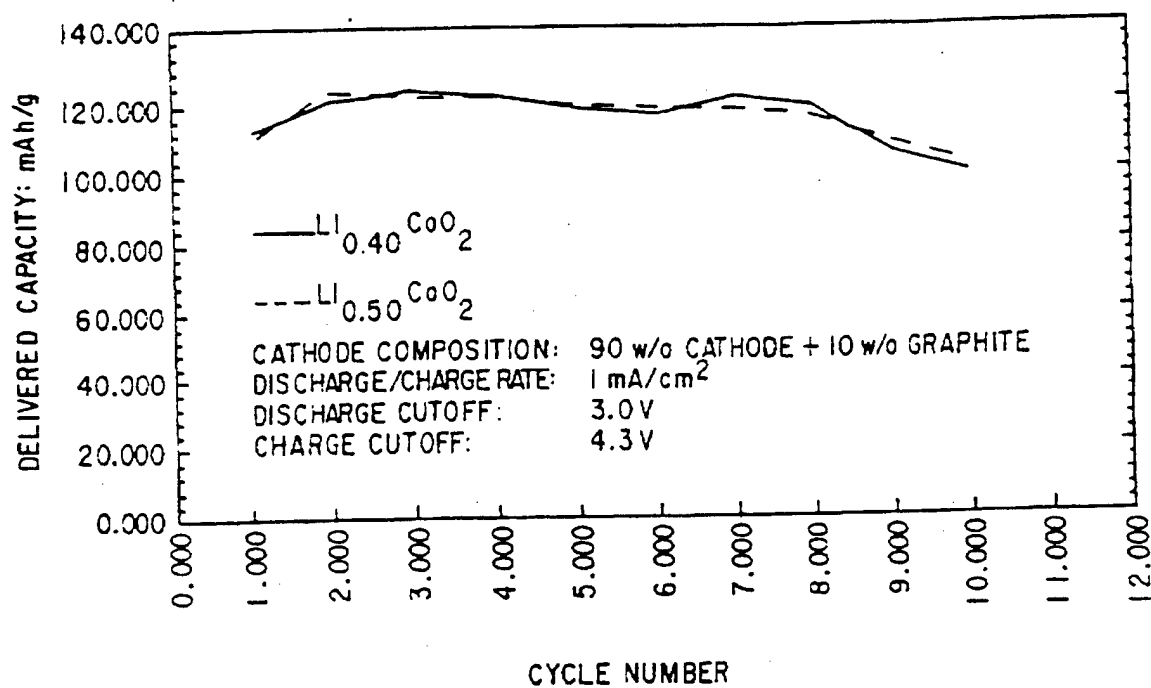


FIG. 2

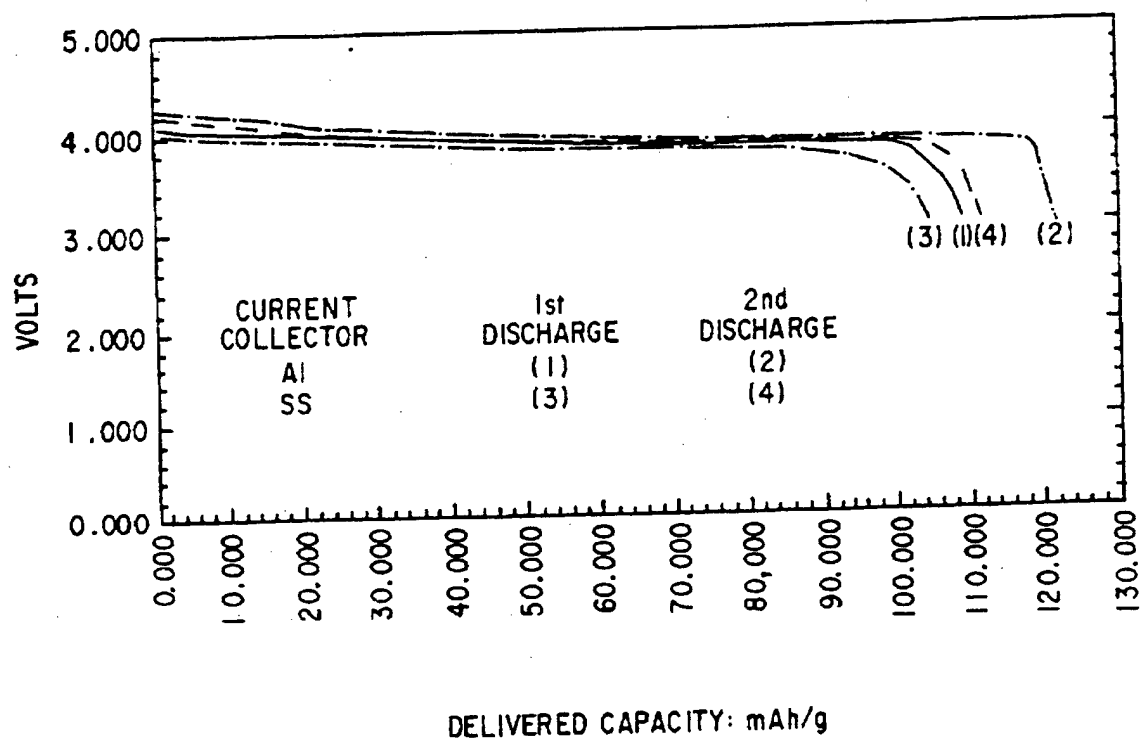


FIG. 3



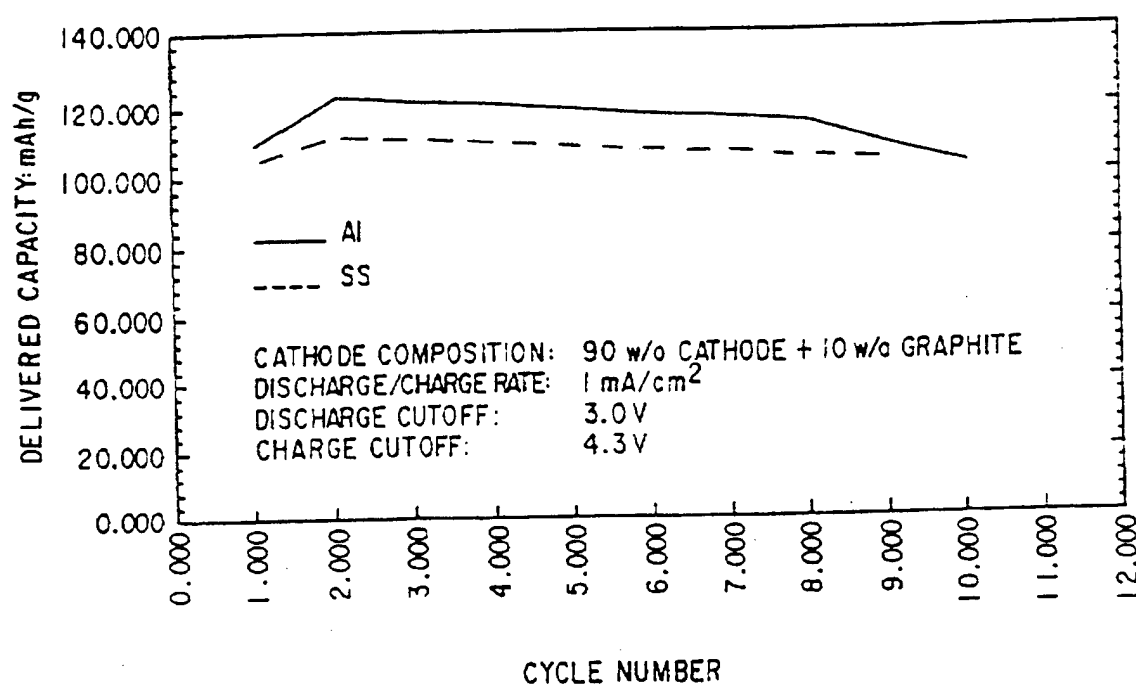


FIG. 4

U.S. Patent

Sep. 16, 1997

Sheet 5 of 5

5,667,660

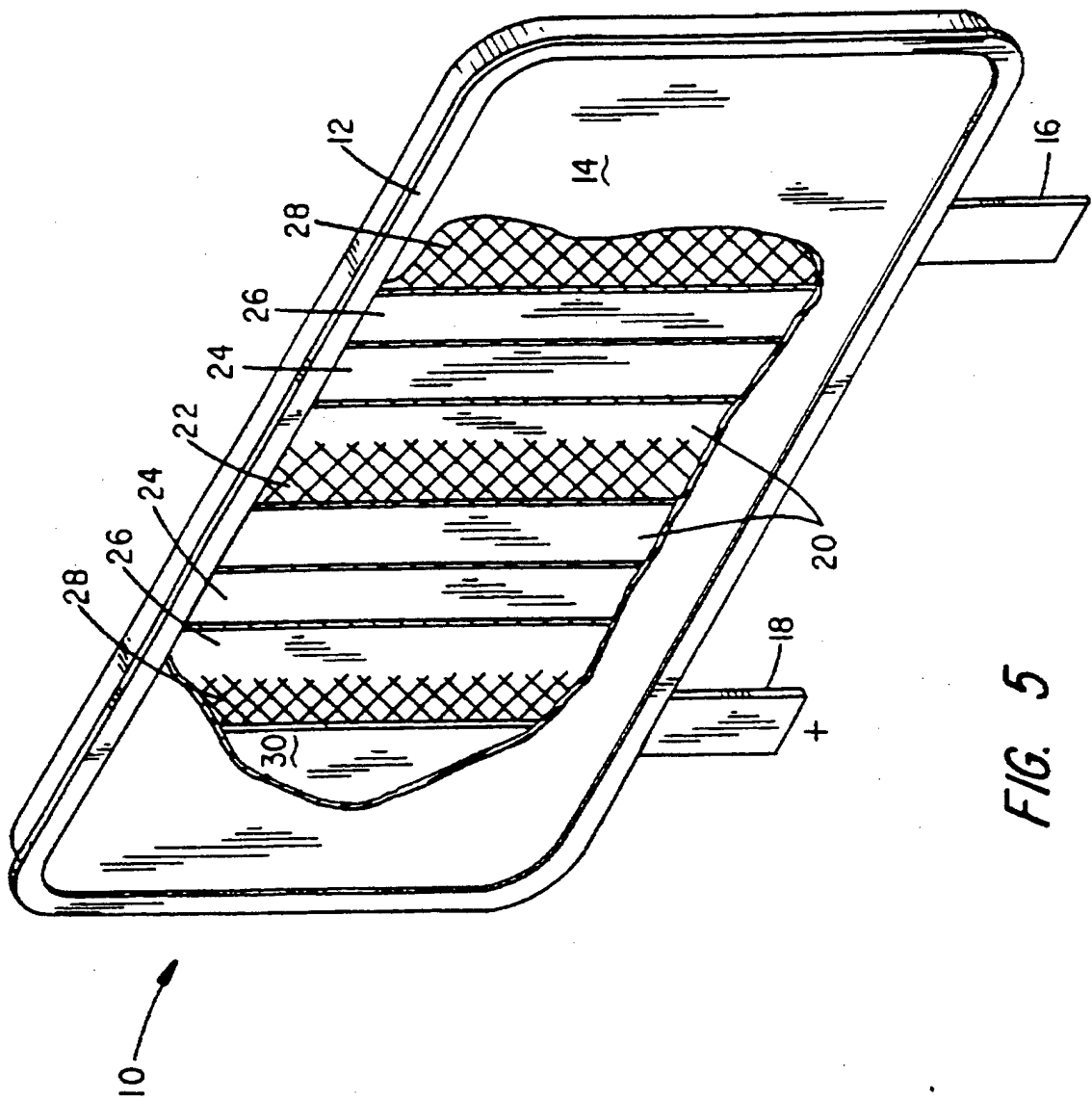


FIG. 5

1

# SYNTHESIS OF CHARGED $\text{Li}_x\text{CoO}_2$ ( $0 < x < 1$ ) FOR PRIMARY AND SECONDARY BATTERIES

## BACKGROUND OF THE INVENTION

The Government has certain rights in this application pursuant to Contract N60921-93-C-0060 with the Department of the Navy.

### 1. Field of the Invention

The present invention is directed generally to the field of high energy, non-aqueous electrochemical cells and, more particularly, to improvements in such cells employing  $\text{Li}_x\text{CoO}_2$  cathode material which enable the cathode material to be synthesized in a pre-charged state prior to incorporation in the cell.

### 2. Related Art

Non-aqueous, active metal cells have become well known for achieving very high energy densities or energy to weight ratios, i.e., higher than was previously known with other types of electrochemical cells. Active metal cells typically consist of a light, strongly reducing anode, normally of an alkali metal such as lithium (an aprotic, non-aqueous solvent into which an appropriate quantity of the salt of the anode metal has been dissolved to form a conductive solution, and an oxidizing agent as the cathode material. Such cells can be in the form of primary or secondary (rechargeable) cells.

It is further known to employ the material  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) as the active cathode material of such cells. For example, its use is disclosed in U.S. Pat. No. 4,497,726 and further discussed in Mizushima, K. et al. " $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ): A New Cathode Material for Batteries of High Energy Density." *Mat. Res. Bull.*, Vol. 15, 783 (1980). A lithium non-aqueous secondary electrochemical cell having an ester-based organic electrolyte solution and a cathode active material comprising  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) is illustrated and described in U.S. Pat. No. 4,804,596 to Walter B. Ebner and Hsiu-Ping W. Lin (an inventor in the present application) which is also assigned to the same assignee as the present application. That reference describes the use of  $\text{Li}_x\text{CoO}_2$  as the active cathode material in a cell in combination with an ester-based electrolyte solution that can withstand the high operating and charging potentials characteristic of that system. The  $\text{Li}_x\text{CoO}_2$  cathode material in that system, however, must be incorporated in the discharged state and thereafter charged. Furthermore, because of corrosion problems in stainless steel, an aluminum grid is required to withstand the initial charging voltage.

Lithium-cobalt oxide ( $\text{LiCoO}_2$ ) and lithium-cobalt-nickel oxides ( $\text{LiCo}_{1-y}\text{Ni}_y\text{O}_2$ ) ( $0 \leq y \leq 1$ ) are described for use as electrodes for rechargeable lithium cells by R. J. Gummow and M. M. Thackeray in "Characterization of LT- $\text{LiCo}_{1-y}\text{Ni}_y\text{O}_2$  Electrodes for Rechargeable Lithium Cells", *J. Electrochem. Soc.*, Vol. 140, No. 12, December (1993). They describe the use of acid leaching to improve the recycling properties of certain materials. Data supplied in the reference for the charge/discharge profiles of acid leached LT (Low Temperature)  $\text{LiCoO}_2$ , however, shows achievement of only about 63 mAh/g for the first discharge and this degrades quickly to <20 mAh/g in only four cycles. Certain Ni doped Li/LT- $\text{LiCoNiO}_2$  cells assembled in a charged state were found to be significantly more cycle tolerant. However, success was limited to Ni doped materials.

Thus,  $\text{Li}_x\text{CoO}_2$  heretofore has been available for incorporation as a successful cathode material only in a fully discharged state because  $\text{Li}_x\text{CoO}_2$  as it is known to exist in

2

the charged state is not stable with respect to elevated temperatures normally required in the manufacturing environment. The batteries have, therefore, been assembled in the discharged state and charged prior to first use. The charging process has certain drawbacks. It results in the plating of an amount of lithium from the cathode onto the anode, and batteries have had to be designed to accommodate the extra lithium plated out of the cathodes during the initial charging after assembly; otherwise, internal shorting of the battery could be a problem. Also, the high voltage required to the initial charging of the battery has required the cathode collector to be made from aluminum rather than the preferred material, stainless steel. Other approaches have been tried to improve the cycle efficiency of  $\text{Li}_x\text{CoO}_2$ . Electrochemical titration has been used on pre-fabricated cathodes to obtain charged  $\text{Li}_x\text{CoO}_2$  material. However, this process has been used with limited success as it produces only limited quantities of charged material and the final products have to be determined by the pre-fabricated shapes and compositions.

Accordingly, it is a primary object of the present invention to provide a synthesis for charged  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) suitable for use as the cathode active material in primary and secondary battery applications.

It is a further object of the present invention to provide a synthesis for charged  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) for primary and secondary cell applications in which the charged material is in a stable powdered form which can then be shaped and incorporated in any composition of cathode desired.

Other objects and advantages with respect to the present invention will occur to those skilled in the art through familiarity with the specification and claims herein.

## SUMMARY OF THE INVENTION

The present invention provides a new cathode process in which charged  $\text{Li}_x\text{CoO}_2$  cathodes can be manufactured in an efficient and cost-effective manner. The product is superior to acid-treated embodiments, delivering twice the capacity of those materials with improved cycling efficiency. The positive current collector for the cathode is not limited to aluminum. It may be stainless steel. The present invention provides a process to manufacture charged  $\text{Li}_x\text{CoO}_2$ , preferably where  $0 \leq x \leq 0.5$ , in a powdered form for use as a raw material in the subsequent manufacture of cathodes. The powdered form can be combined in any desired cathode composition and worked into any configuration or shape.

In the preferred process, pure  $\text{LiCoO}_2$  commercially obtainable from FMC Corporation, for example, is used as the starting material. A small amount of solvent, for example, methyl formate (MF) is added to the  $\text{LiCoO}_2$  powder to wet the powder and to form a wet slurry or paste. The material is then formed as a layer on a pre-cut metal grid, preferably of aluminum, and suitably provided with an electrical lead, and the surface thereafter smoothed. The pasted material is then sealed inside microporous separators which may be a polyethylene envelope which is itself thereafter sandwiched between two sections of lithium anode of approximately the same dimensions also provided with electrical connections. The three-plate stack which itself forms a large lithium cell is then confined in an alluminated trilaminated envelope with anode and cathode leads protruding out from the envelope. Next, electrolyte is injected into the bag and the large cell charged. After charging the desired amount, the cell is opened in a dry room and the cathode envelope opened and the material rinsed with solvent and vacuum dried.

3

The charged  $\text{Li}_x\text{CoO}_2$  powder is now ready to be removed from the original aluminum charging grid and utilized in a cathode mixture in any manner desired. The value of  $x$  can be controlled by the amount of coulombic titration, and is preferably less than about 0.5.

The charged material is still in powdered form and can be used as raw cathode material for any batteries. The material is normally mixed with a conductive diluent such as carbon or graphite in a binder such as polytetrafluoroethylene (PTFE) and the cells can be used for primary or secondary applications without initial charging.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 represents the discharge performance of cells using the pre-charged  $\text{Li}_{0.5}\text{CoO}_2$  cathodes in accordance with the invention at two discharge rates, 1 and 5 mA/cm<sup>2</sup>:

FIG. 2 is a graphical representation of cycle performance of pre-charged  $\text{Li}_{0.5}\text{CoO}_2$  cells over ten cycles;

FIG. 3 is a discharge plot of pre-charged  $\text{Li}_{0.5}\text{CoO}_2$  cells at 1 mA/cm<sup>2</sup> rate comparing aluminum and stainless steel current collectors:

FIG. 4 shows cycle performance of pre-charged  $\text{Li}_{0.5}\text{CoO}_2$  cathode cells over ten cycles comparing aluminum and stainless steel current collectors; and

FIG. 5 is a perspective schematic view with parts broken away of a charging system for producing pre-charged  $\text{Li}_x\text{CoO}_2$  in accordance with the invention.

#### DETAILED DESCRIPTION

The present invention enables the advantages associated with the unusually high energy density of  $\text{Li}_x\text{CoO}_2$  cathode material to be incorporated in a pre-charged state by subjecting it to a pre-charging process prior to incorporation in the cathode mixture. The process makes use of  $\text{Li}_x\text{CoO}_2$  in the uncharged state and transforms it into a pre-charged  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) powdered raw cathode material for incorporation in a cathode mix suitable for any battery, primary, secondary, etc. in which such cathode material is desired. As a powder, the material can be worked into any shape or mixture combination required.

A system for pre-charging the  $\text{LiCoO}_2$  powder for use as the cathode active material according to the invention is depicted in FIG. 5. The charging system generally takes the form of a rather large lithium cell shown generally at 10 and includes a metallic retaining shell having a retaining rim as shown at 12 which may be stainless steel and which further supports a metallized plastic bag 14, preferably a trilaminated envelope having an aluminized inner surface (not shown). Protruding anode and cathode leads shown respectively at 16 and 18 are designed for external connection to a source of charging voltage. The  $\text{LiCoO}_2$  20 is pressed onto both sides of the metallic grid, preferably aluminum, 22. Grid 22 which with a pair of semipermeable microporous polymer separators 24 is sandwiched between a pair of lithium anodes 26 with metallic, preferably nickel, current collectors 28. This forms what is known as a three-plate stack cell with the cathode material sandwiched between a pair of large area anodes. This may be covered by a layer of material such as Tefzel 30 within the trilaminated metallized envelope 14.

In the preferred embodiment of the process, finely divided  $\text{LiCoO}_2$  powder, approximately -325 mesh, obtained in a substantially pure form from FMC Corporation, is combined with a small amount of solvent, such as methyl formate

4

(MF), to form a heavy slurry or paste. The paste is then spread onto both sides of the pre-cut metallic grid 22 which is of a metal which can withstand the required charging voltage without corroding, such as aluminum. The thickness of the paste is typically 0.25" and that of the grid is 0.01". The surface of the paste may be made generally smooth using a stainless steel plate, or the like. The pasted material is then sealed inside separators 24 which may each be a layer of microporous polymer material, normally a polyethylene envelope, represented by separators which itself is thereafter sandwiched between the pair of lithium anodes 26 with nickel grids 28. This sandwich or three-plate stack is thereafter confined inside the metallized (aluminized) trilaminated envelope (which may be polyethylene terephthalate). An electrolyte material is then injected into the bag to activate the cell. The electrolyte is preferably a 2 molar double salt methyl formate ( $\text{LiAsF}_6 + \text{LiBF}_4$ ) system but any suitable material including methyl acetate may be employed. The cell is typically charged at a potential of 4.3 volts. After charging, one trilaminated envelope was opened in a dry room and the internal cathode envelope cut open and the material rinsed with solvent and vacuum dried. The result was a charged  $\text{Li}_x\text{CoO}_2$  powder in ready-to-use form in which the value of  $x$  can be controlled by the amount of coulombic titration and is preferably less than 0.5.

The typical grid size used experimentally has been about 9 cm by 19 cm which can process about 100 grams of  $\text{LiCoO}_2$ . This is enough material for about 25 size "AA" rechargeable  $\text{Li}_{0.5}\text{CoO}_2$  cells. The system works well for fairly high production rates. The normal charging voltage is about 4.3V and about 5 mA of current. The metallized trilaminated envelope may be any compatible gas-tight system which is easy to apply and remove in the process.

As can be seen from the above, the construction of the cell charging system is simple and inexpensive and the charged material requires no special handling. Desired quantities of conductive diluent, such as carbon or graphite, and binder, such as polytetrafluoroethylene (PTFE), can be added and the material processed into the finished cathode. Such cathodes, of course, can be used for primary or secondary applications without the initial charging  $\text{LiCoO}_2$  requires.

The discharge performance of pre-charged  $\text{Li}_{0.5}\text{CoO}_2$  cathodes is depicted in FIG. 1 for the discharge rates of 1 and 5 mA/cm<sup>2</sup>. In addition, the delivered capacity, which was 113 mAh/g based on total cathode weight, is quite comparable to the typical delivered capacity of approximately 120 mAh/g  $\text{LiCoO}_2$  after charging a cell manufactured in the discharge state. FIG. 2 confirms that the material is cyclable and so suitable for use in secondary cells.

The materials as processed in accordance with the present invention represent a drastic improvement over the acid leached materials previously known and are comparable to materials utilized in the cells previously assembled in the uncharged state. In addition, the positive current collector material for the cathode need not be limited to aluminum in the case of the pre-charged material and can be made from stainless steel or other materials. It had previously been found that stainless steel corroded because of the high required charging voltages in cells built with the discharged  $\text{LiCoO}_2$  cathodes. FIGS. 3 and 4 compare cells utilizing aluminum and stainless steel positive current collectors. FIG. 3 depicts discharge performance of pre-charged  $\text{Li}_{0.5}\text{CoO}_2$  at 1 mA/cm<sup>2</sup> during four discharge cycles. The Figure shows that results are comparable using either material as the positive current collector. FIG. 4 makes a similar comparison for secondary cell cycling and indicates that either material would also be satisfactory in this respect.

5

This invention has been described herein in considerable detail in order to comply with the Patent Statutes and to provide those skilled in the art with the information needed to apply the novel principles and to construct and use embodiments of the example as required. However, it is to be understood that the invention can be carried out by specifically different devices and that various modifications can be accomplished without departing from the scope of the invention itself.

We claim:

1. A method of preparing a cathode incorporating heat stabilized charged  $\text{Li}_x\text{CoO}_2$  as the cathode active material comprising the steps of:

(a) preparing the cathode active material by:

- (1) providing a layer of particulate  $\text{Li}_x\text{CoO}_2$  on a metallic current collector.
- (2) subjecting the  $\text{Li}_x\text{CoO}_2$  on said current collector to a charging current voltage to plate out Li and produce charged  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ), and
- (3) separating the charged particulate material from said current collector; and

(b) incorporating said particulate cathode active material in the cathode.

2. The method of claim 1 wherein ( $0 < x \leq 0.5$ ) after charging.

3. The method of claim 1 wherein the charging voltage is from about 4.2 to about 4.3 volts.

4. The method of claim 1 wherein said current collector is aluminum.

5. The method of claim 1 wherein said charged particulate material is combined with quantities of a conductive diluent material.

6. The method of claim 5 wherein said diluent material is a form of carbon.

6

7. The method of claim 5 further comprising the step of combining said charged particulate material with a binder.

8. The method of claim 6 wherein said charged particulate material is further applied to a stainless steel current collector material.

9. The method of claim 7 wherein said charged particulate material is further applied to a stainless steel current collector material.

10. A method of preparing a cathode containing heat stabilized, charged  $\text{Li}_x\text{CoO}_2$  ( $0 < x < 1$ ) as the active material comprising the steps of:

(a) preparing the active material by:

- (1) creating a layer of powdered  $\text{Li}_x\text{CoO}_2$  from a solvent slurry thereof on a metallic collector grid.
- (2) sandwiching the collector grid between a pair of lithium members separated by semipermeable separator membranes to form a three-plate stack.
- (3) confining the three-plate stack cell in a gas-tight environment.
- (4) providing electrolyte to the three-plate stack;
- (5) charging the cell using externally supplied power until an amount of charge corresponding to a value of  $x$ , where  $0 < x < 1$  is achieved, and
- (6) separating the charged particulate material from said collector grid; and

(b) combining said separated charged particulate  $\text{Li}_x\text{CoO}_2$  material into a cathode mix for application to a current collector for use in a non-aqueous electrochemical cell.

11. The method of claim 10 wherein the gas-tight environment is a metallized coated polymer envelope.

12. The method of claim 10 wherein the metallic collector grid is aluminum.

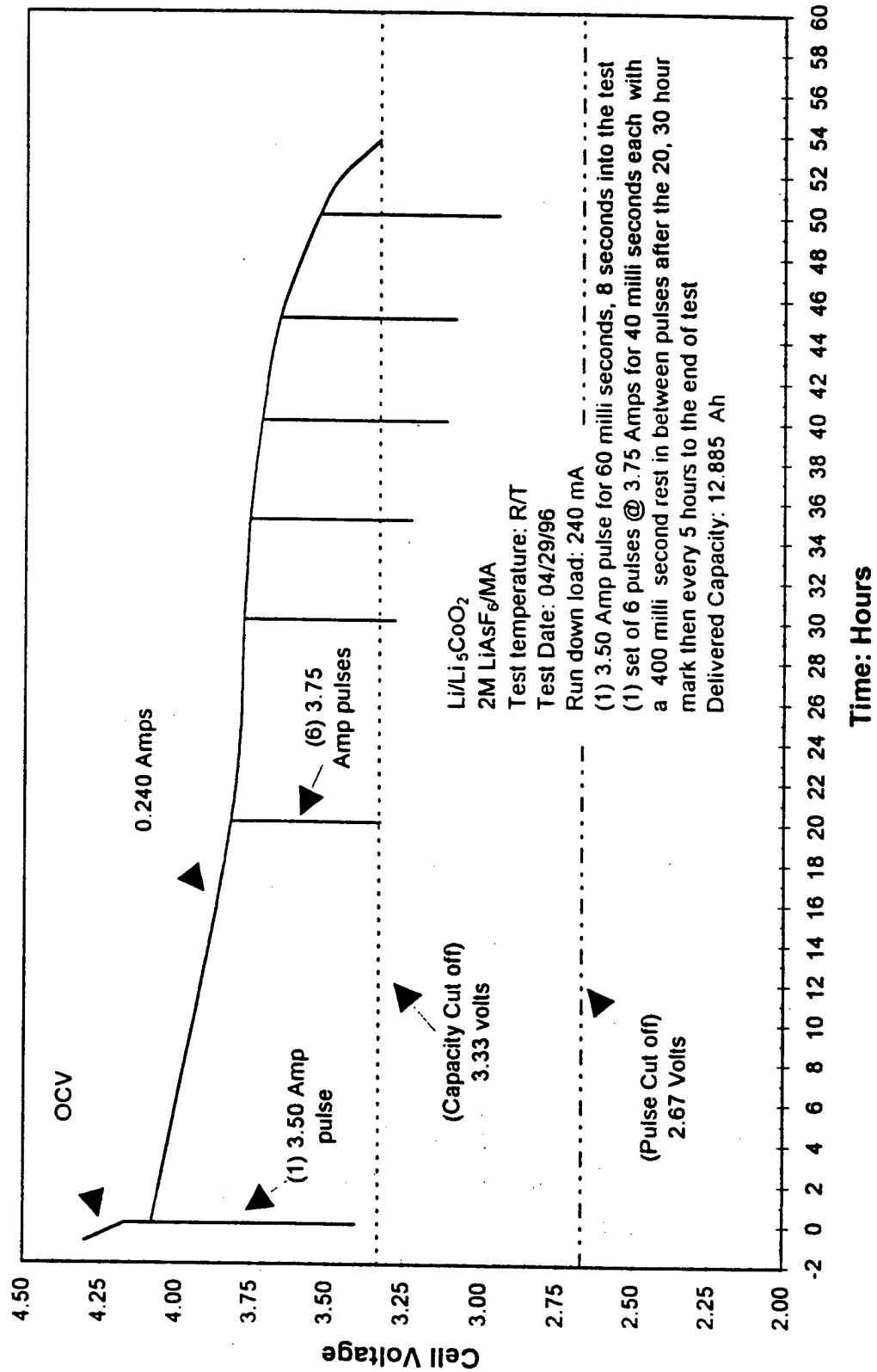
13. The method of claim 10 where  $x \leq 0.5$  after charging.

\* \* \* \* \*

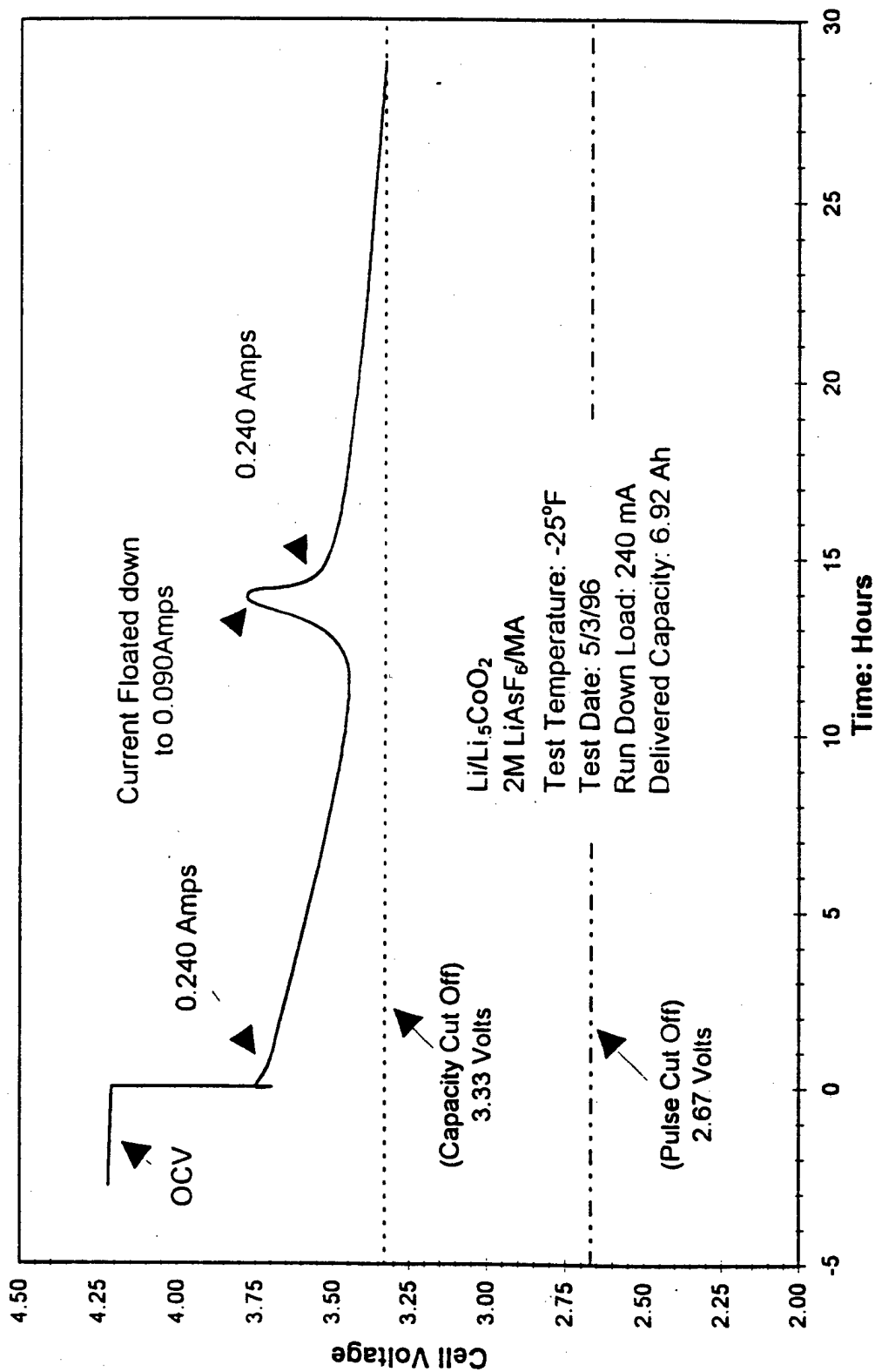
**Appendix C**

**Compilation of Hermetic Cell Test Results**

# Pulse and Capacity Run Down Profile, Cell WAMH02



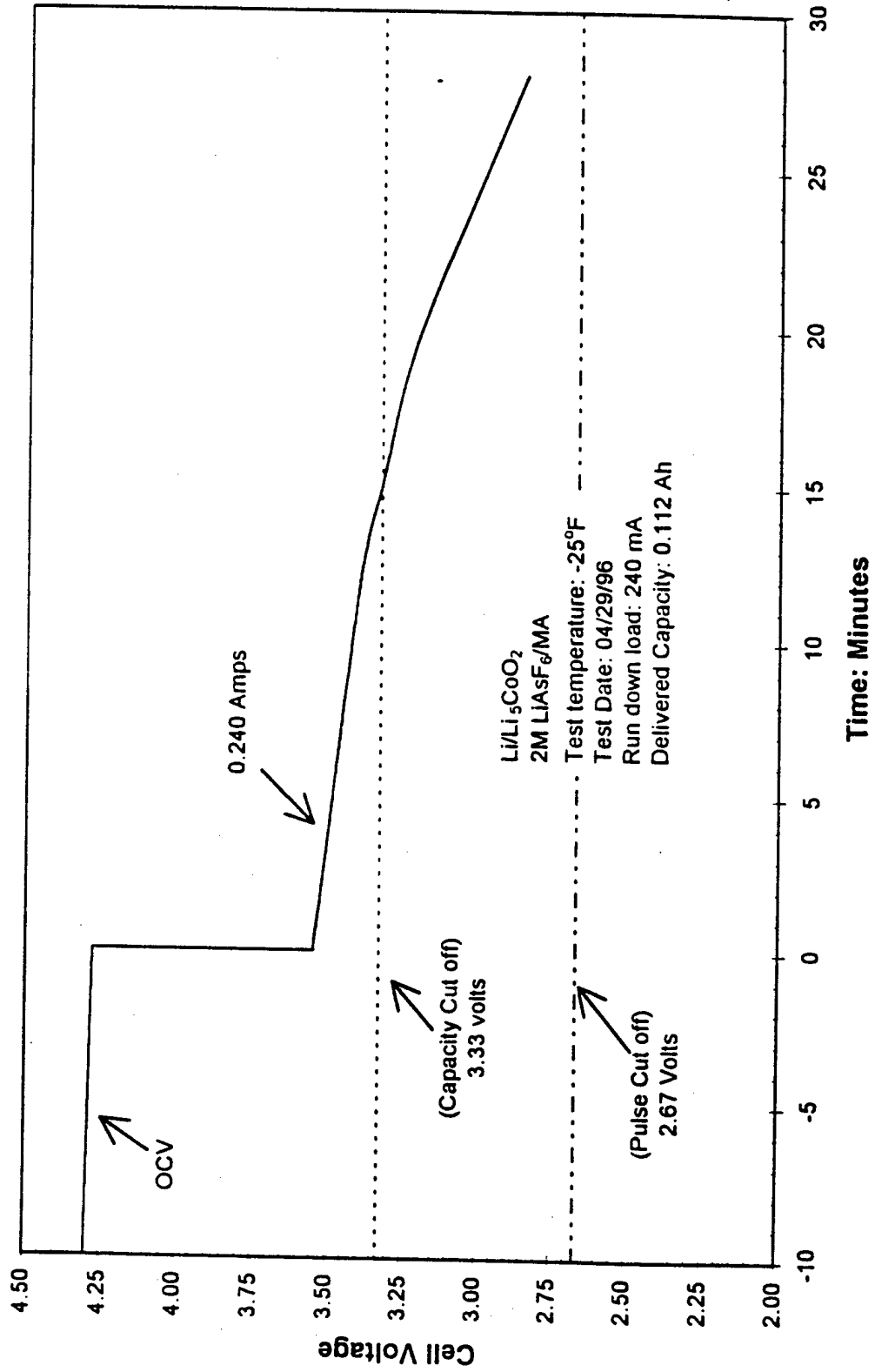
## Pulse and Capacity Run Down Profile, Cell WAMH10





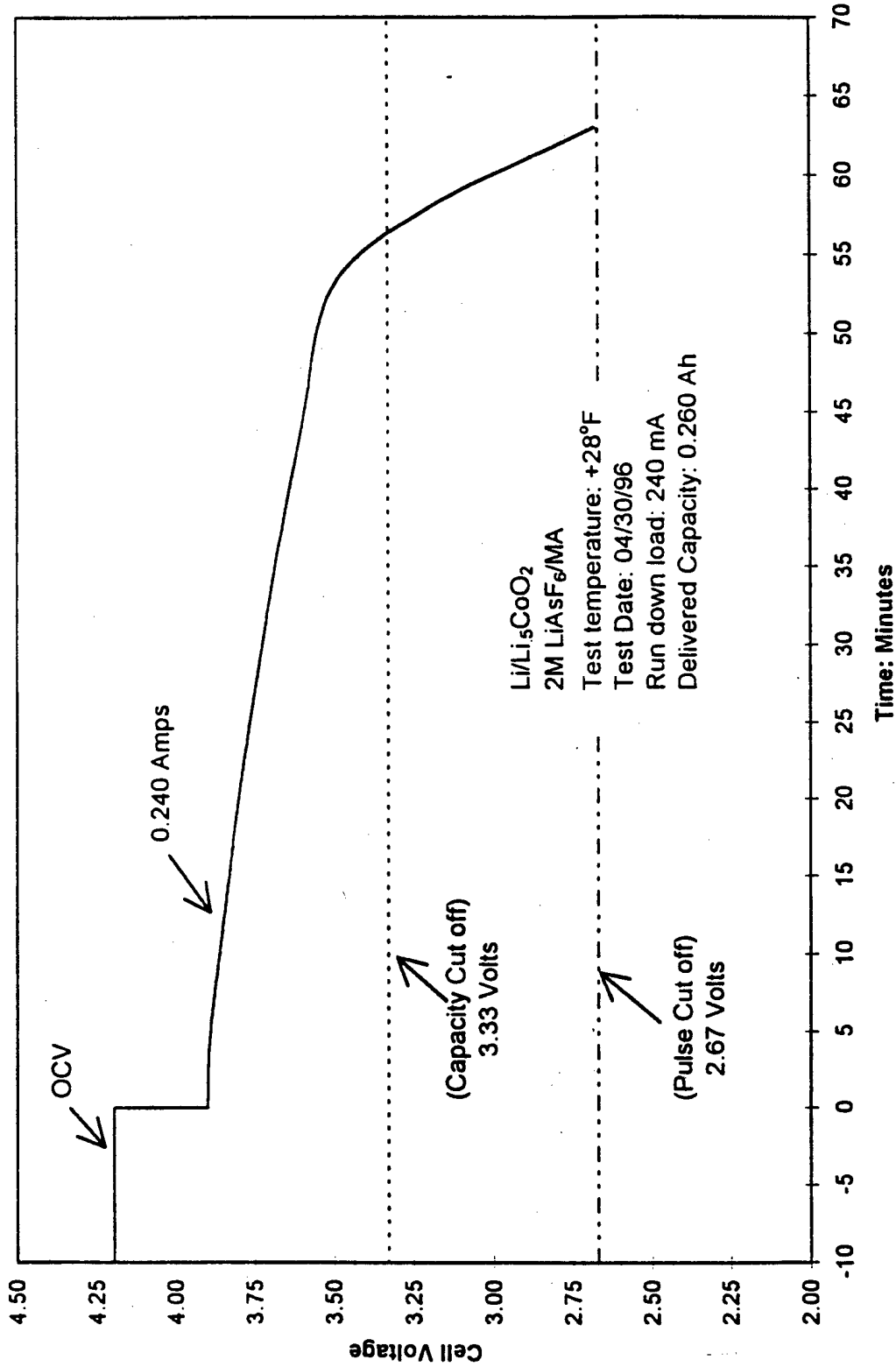
# Pulse and Capacity Run Down Profile, Cell WAMH11

page 1 of 3



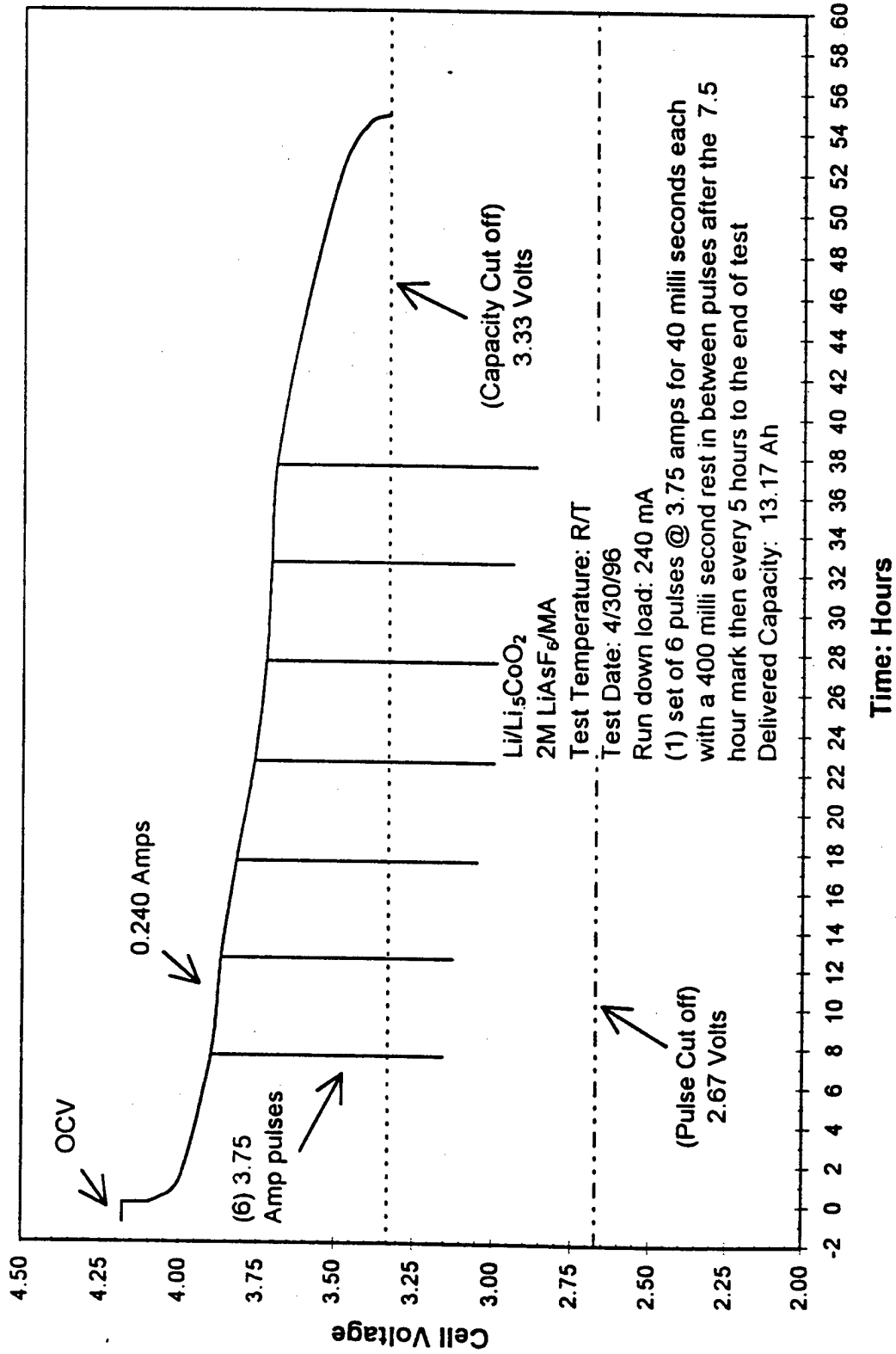
# Pulse and Capacity Run Down Profile, Cell WAMH11

page 2 of 3

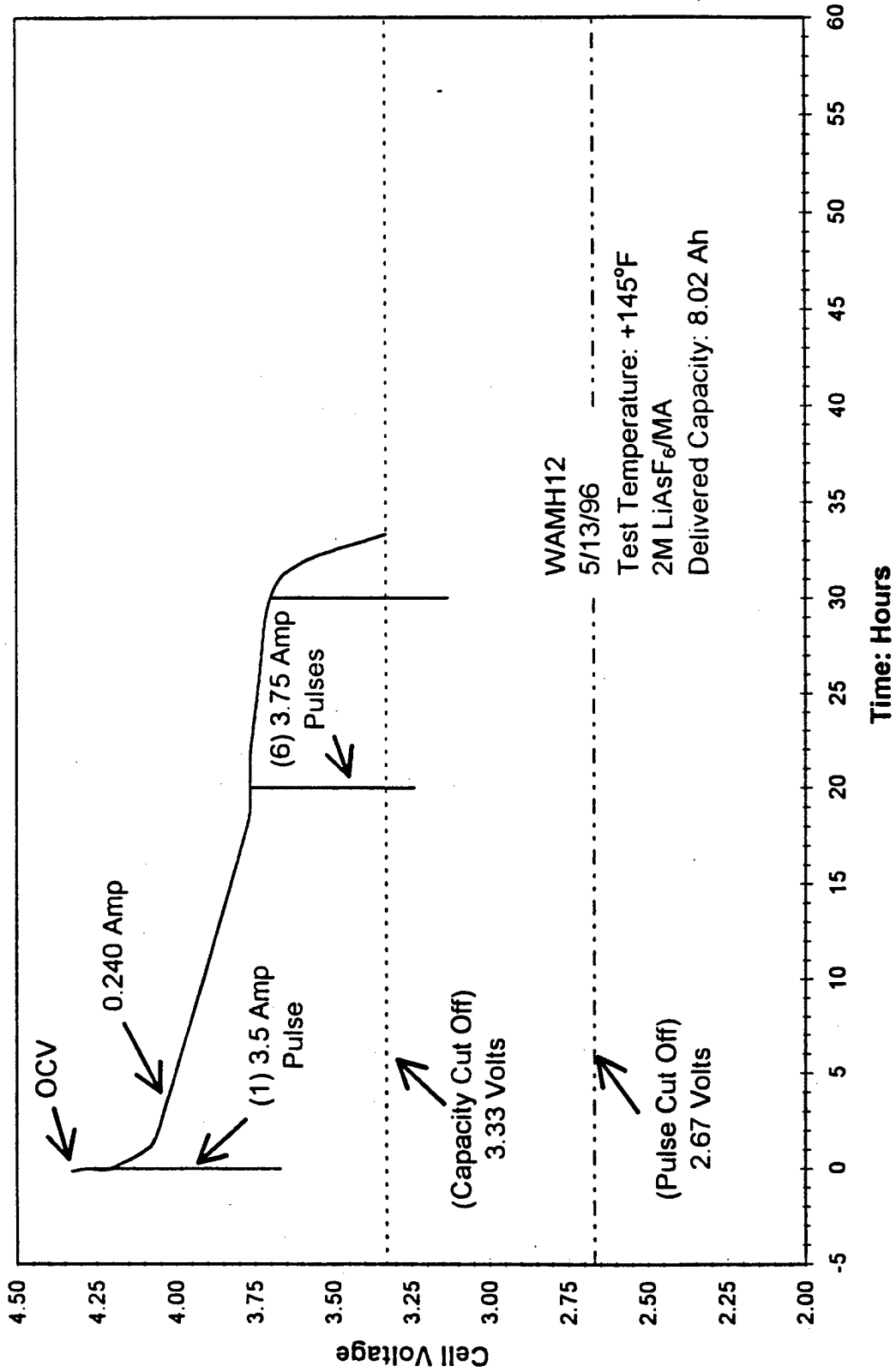


# Pulse and Capacity Run Down Profile, Cell WAMH11

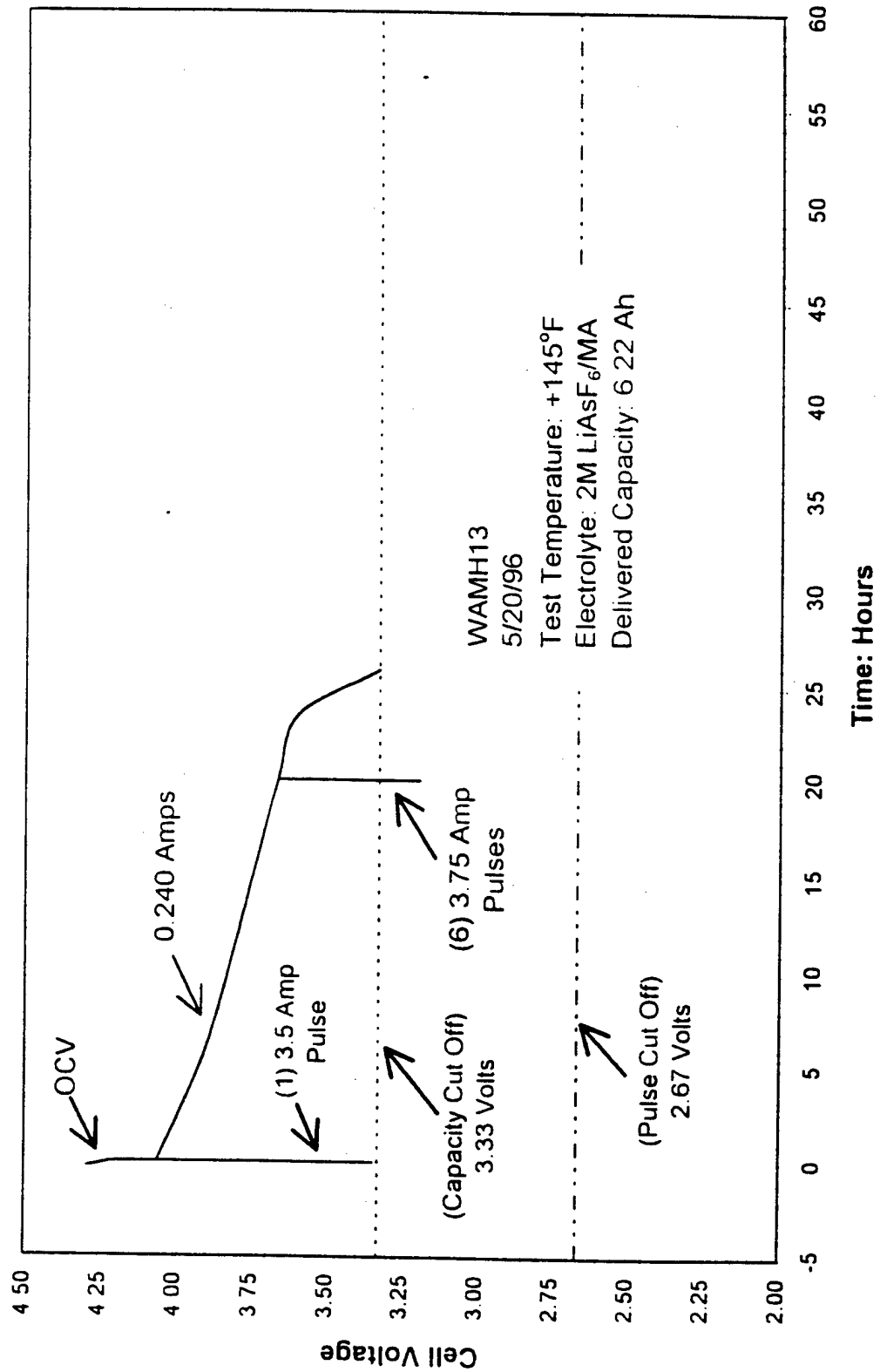
page 3 of 3



# Pulse and Capacity Run Down Profile, WAMH12

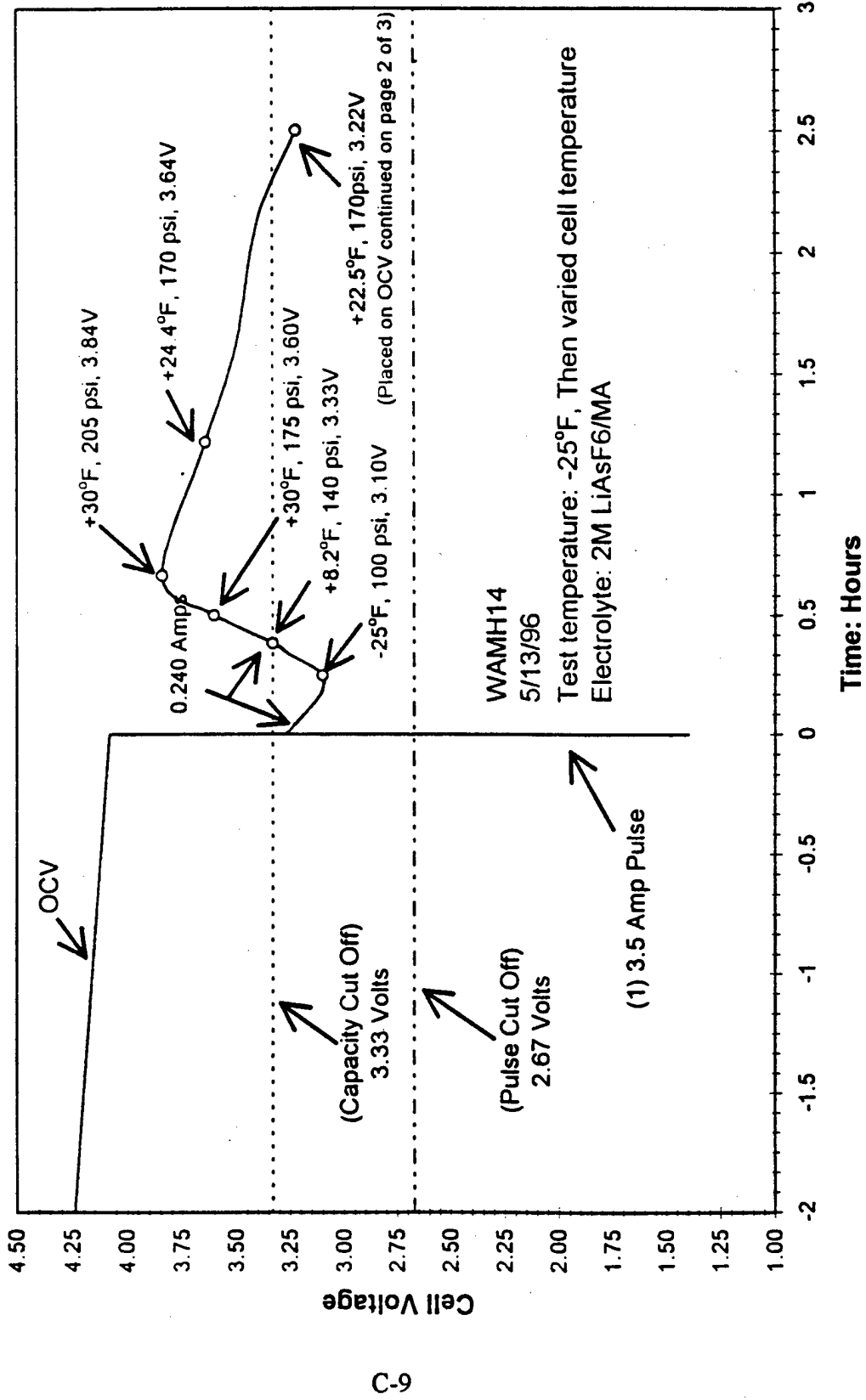


# Pulse and Capacity Run Down Profile, WAMH13



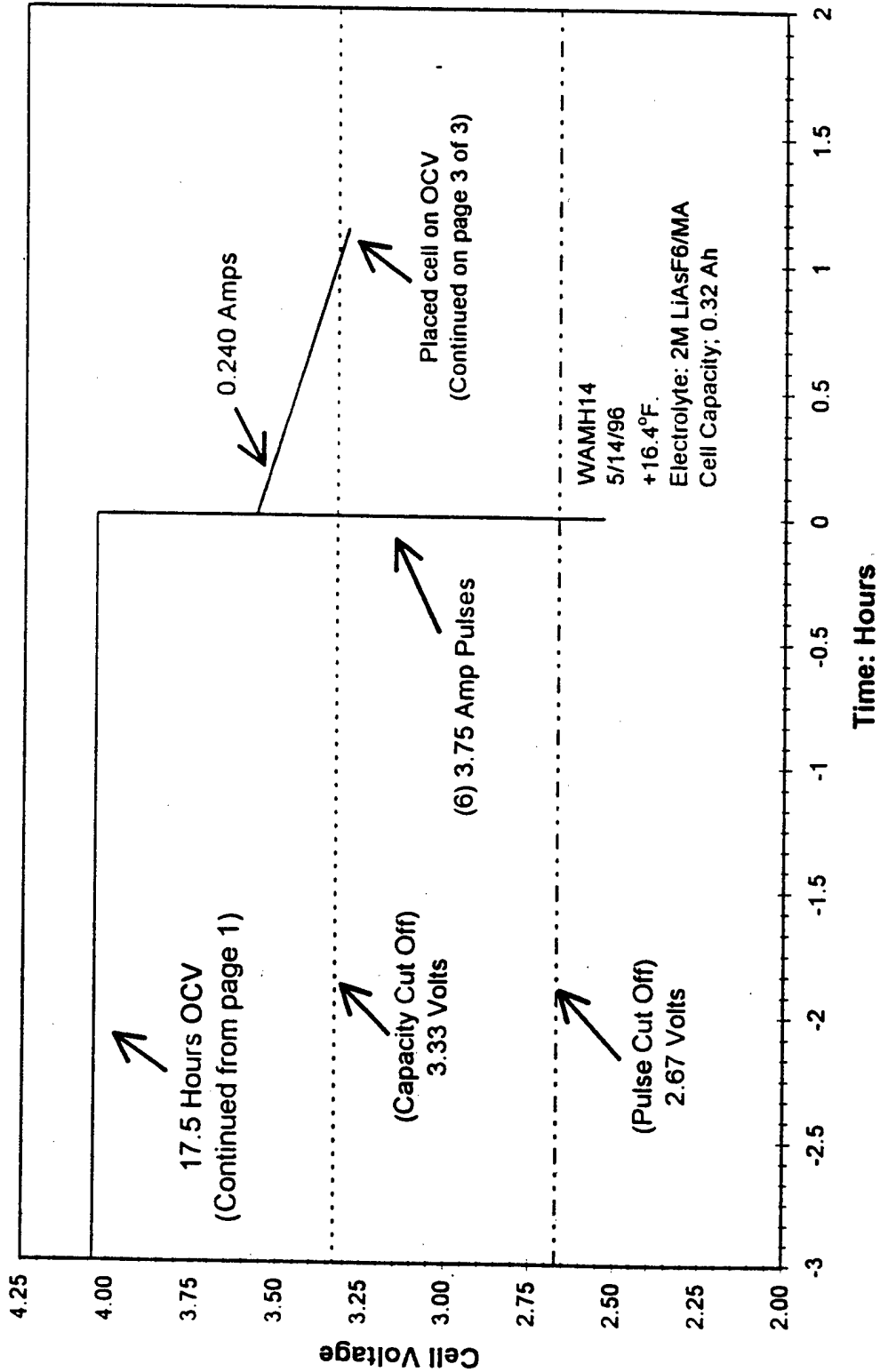
# Pulse and Capacity Run Down, WAMH14

Page 1 of 3



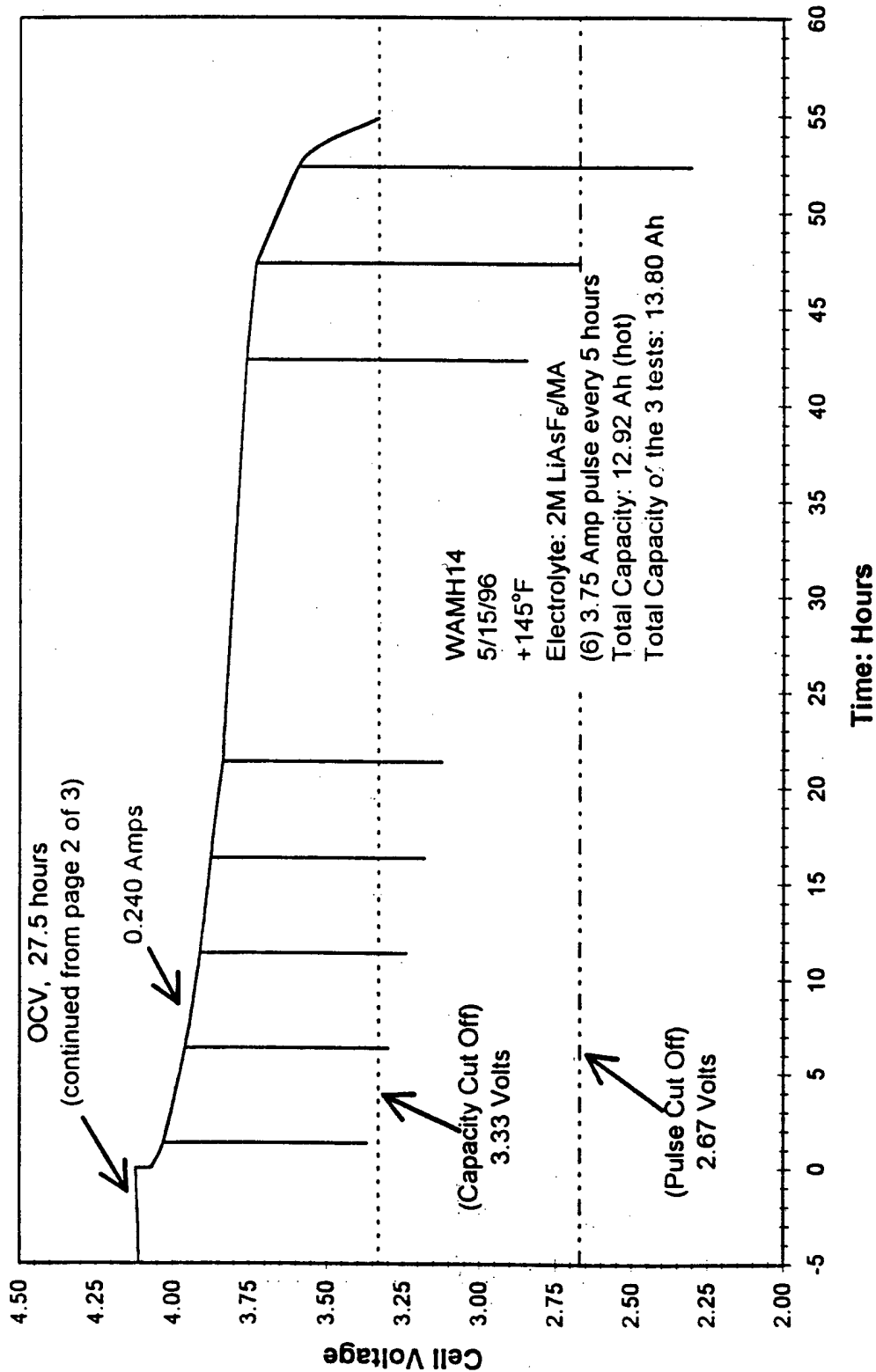
# Pulse and Capacity Run Down, WAMH14

Page 2 of 3



# Pulse and Capacity Run Down Profile, WAMH14

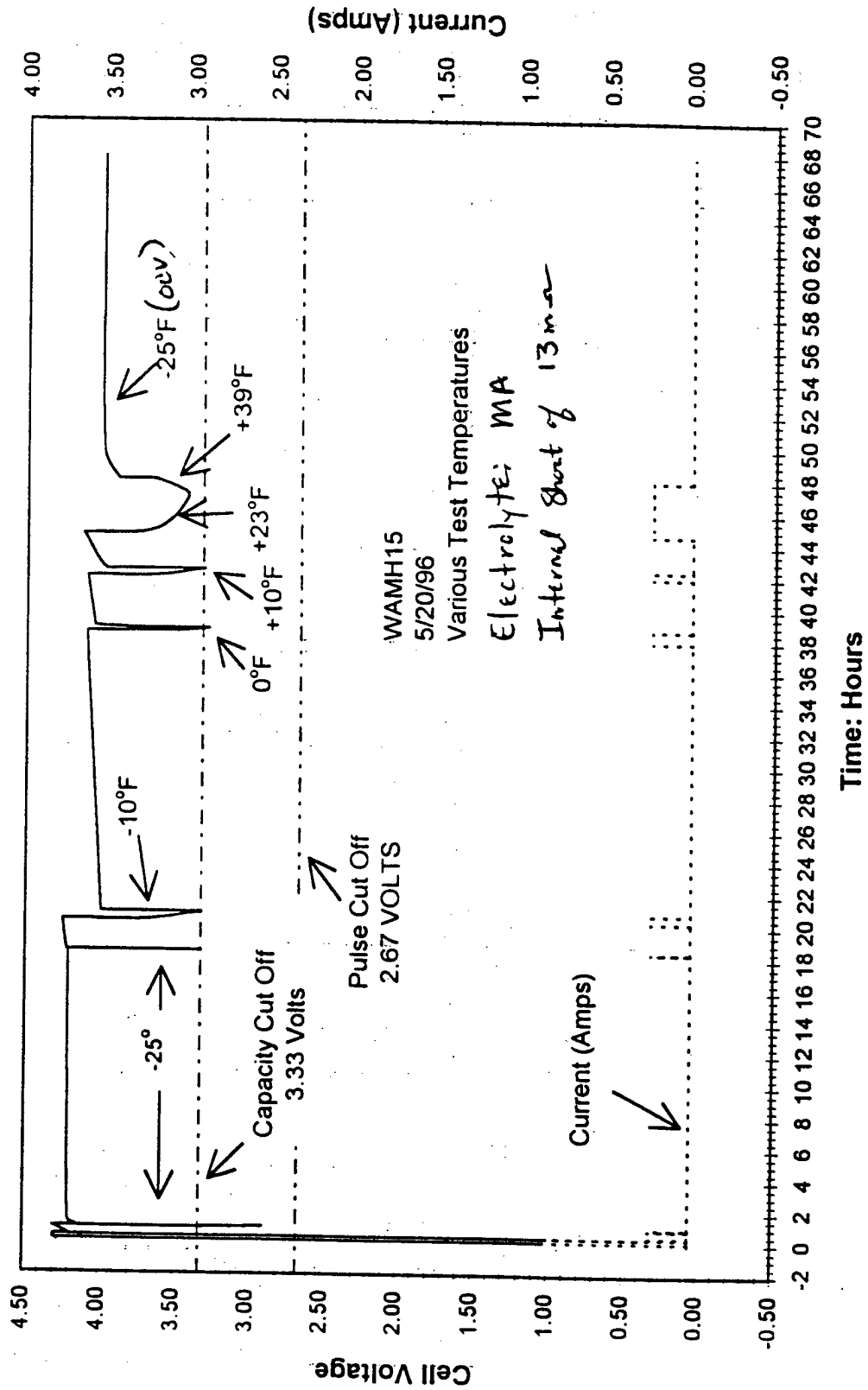
Page 3 of 3





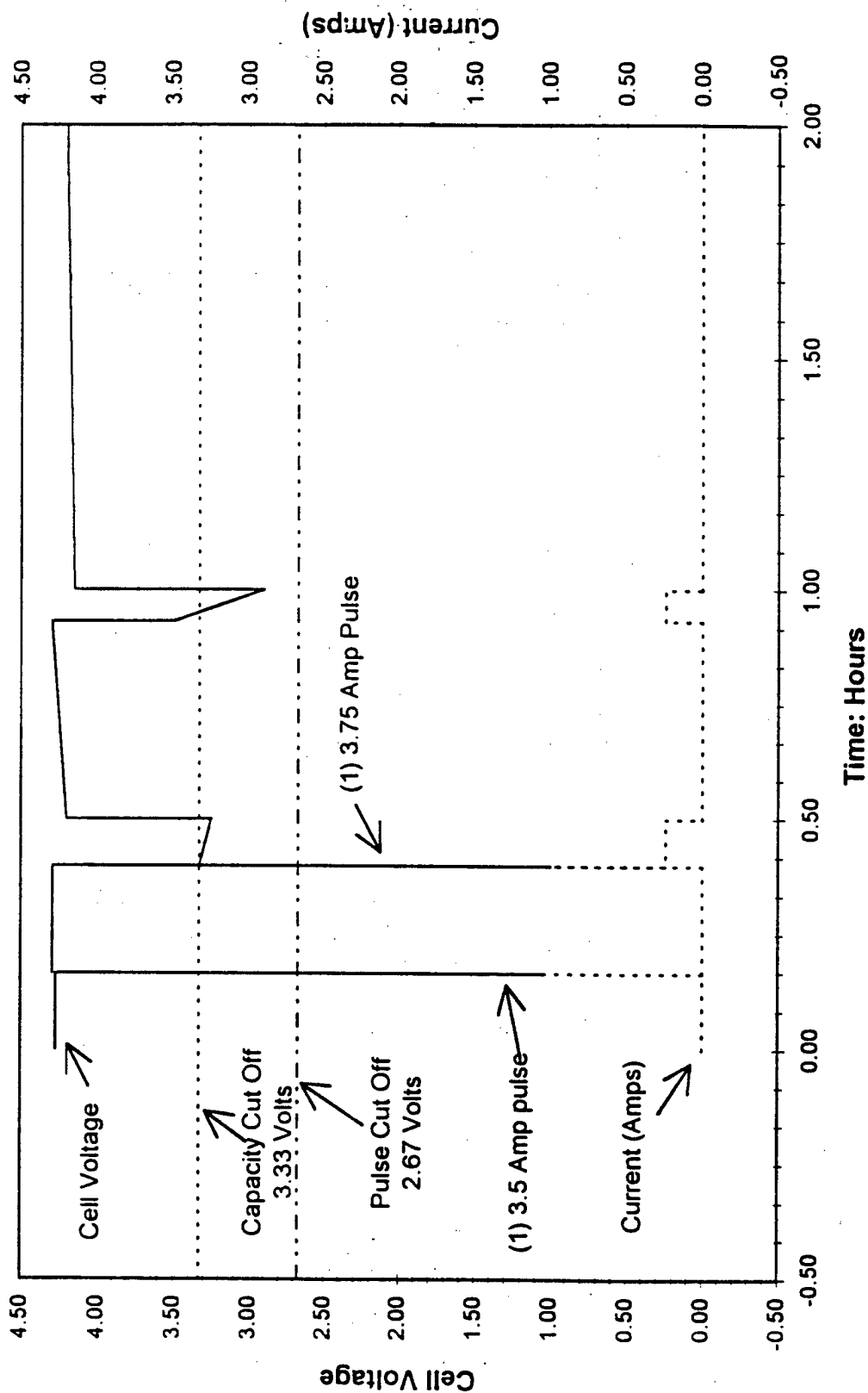
# Pulse and Capacity Run Down Profile, WAMH15

Page 1 of 5



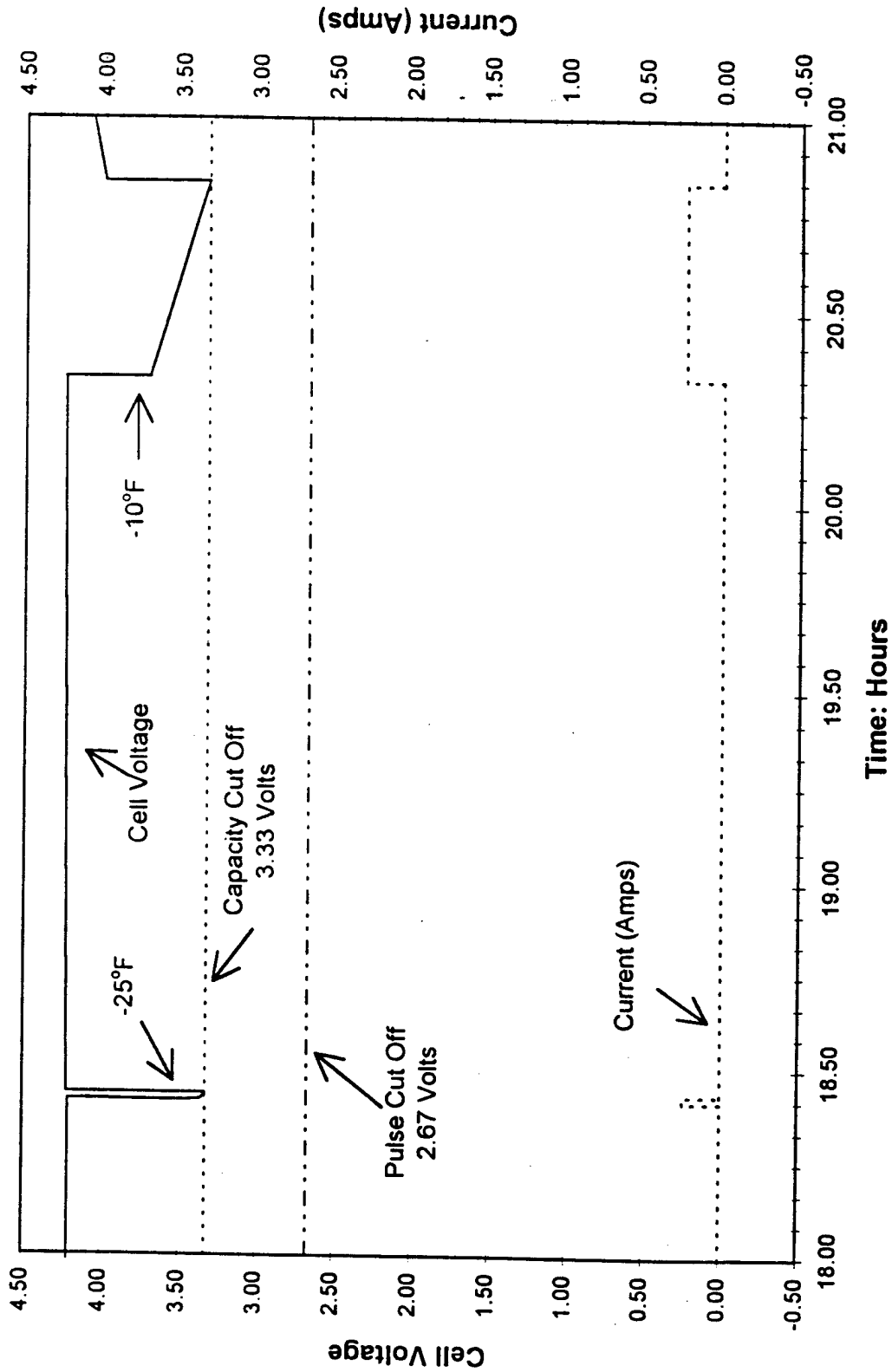
# Pulse and Capacity Run Down Profile, WAMH15

page 2 of 5

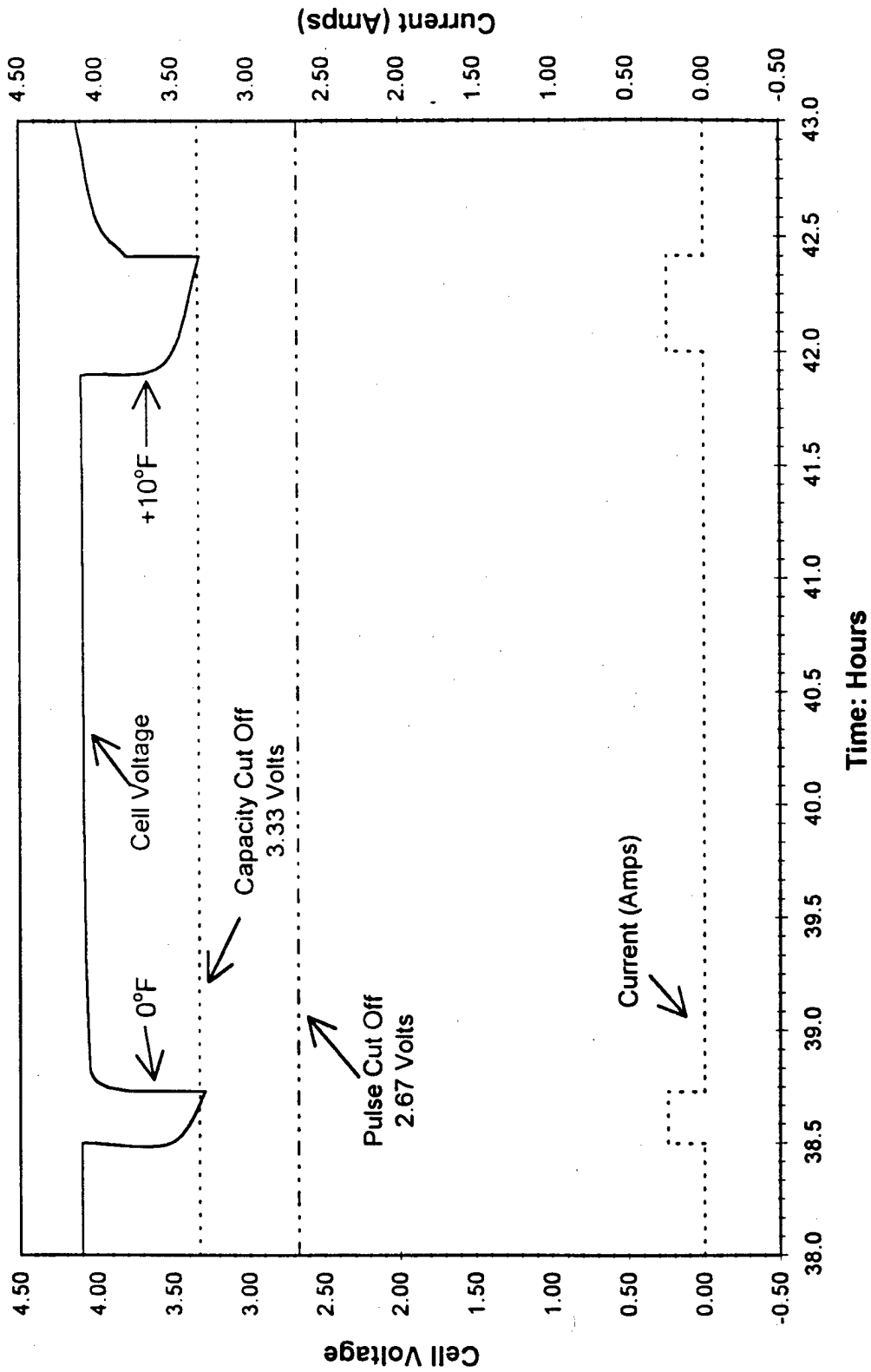


# Pulse and Capacity Run Down Profile, WAMH15

page 3 of 5

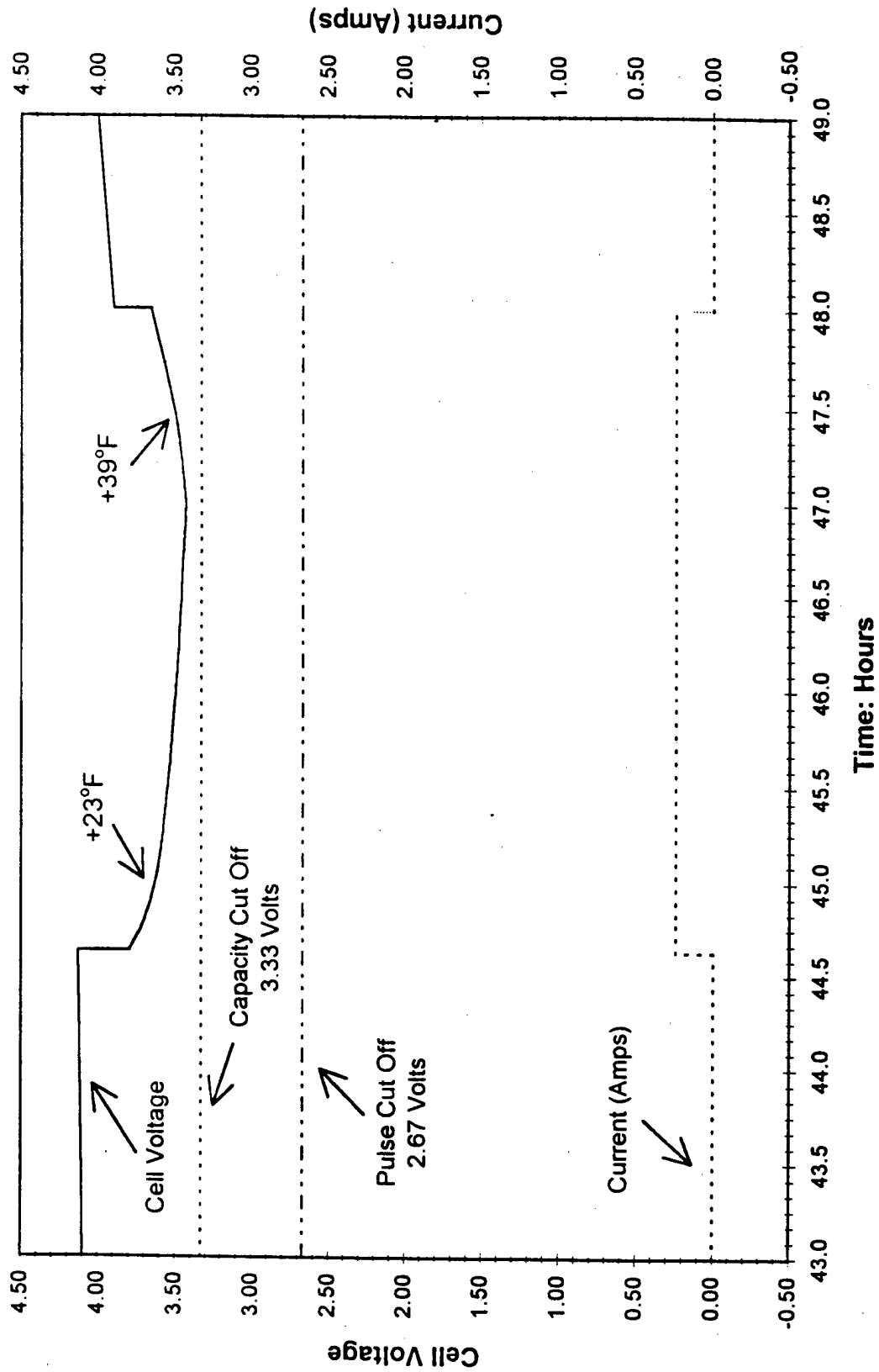


# Pulse and Capacity Run Down Profile, WAMH15 page 4 of 5

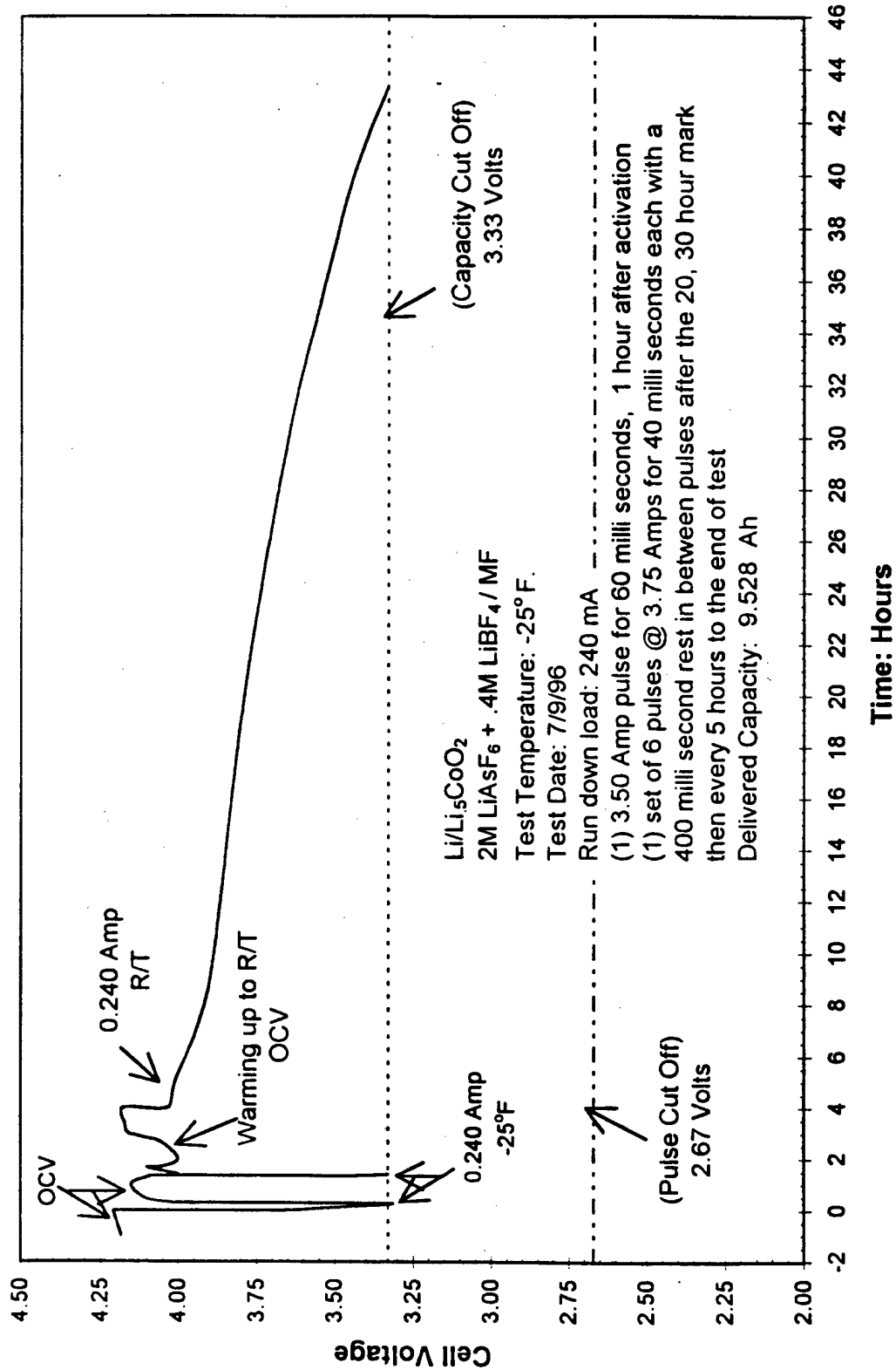


# Pulse and Capacity Run Down Profile, Cell WAMH15

page 5 of 5

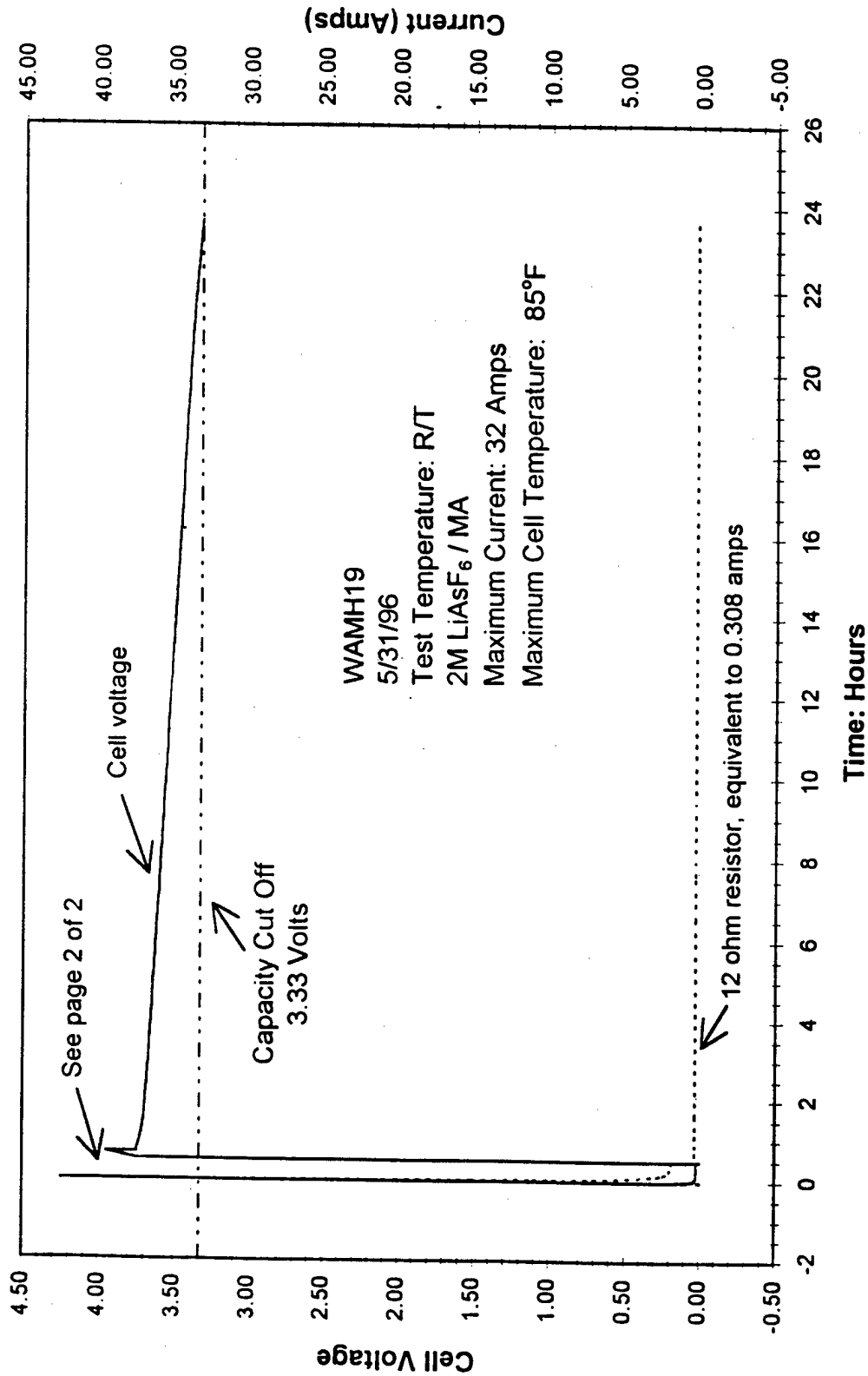


# Pulse and Capacity Run Down Profile, WAMH16 3 Month Storage @ R/T



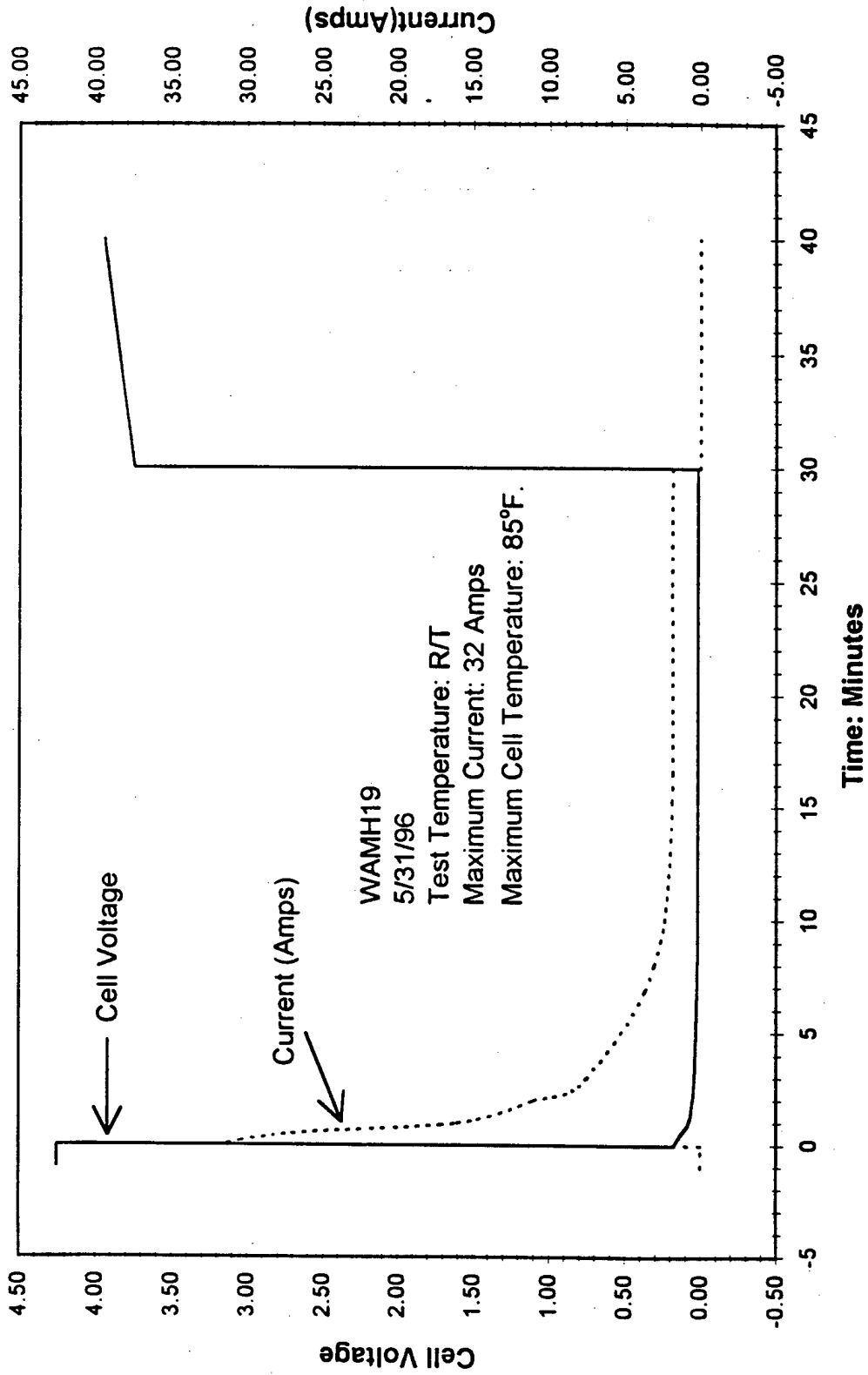
# External Short Circuit Test, WAMH19

page 1 of 2



# H-WAM External Short Circuit Test, WAMH19

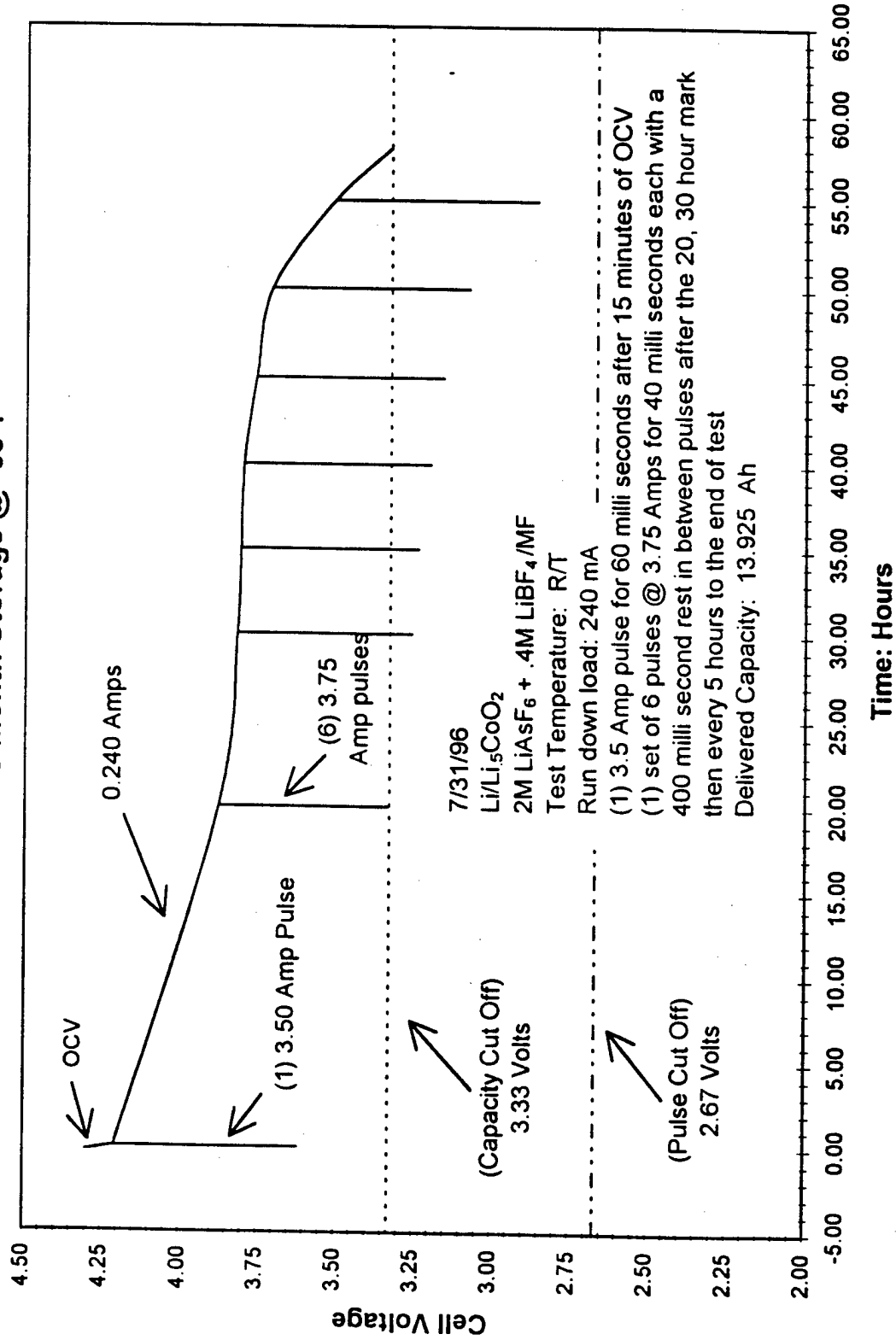
page 2 of 2





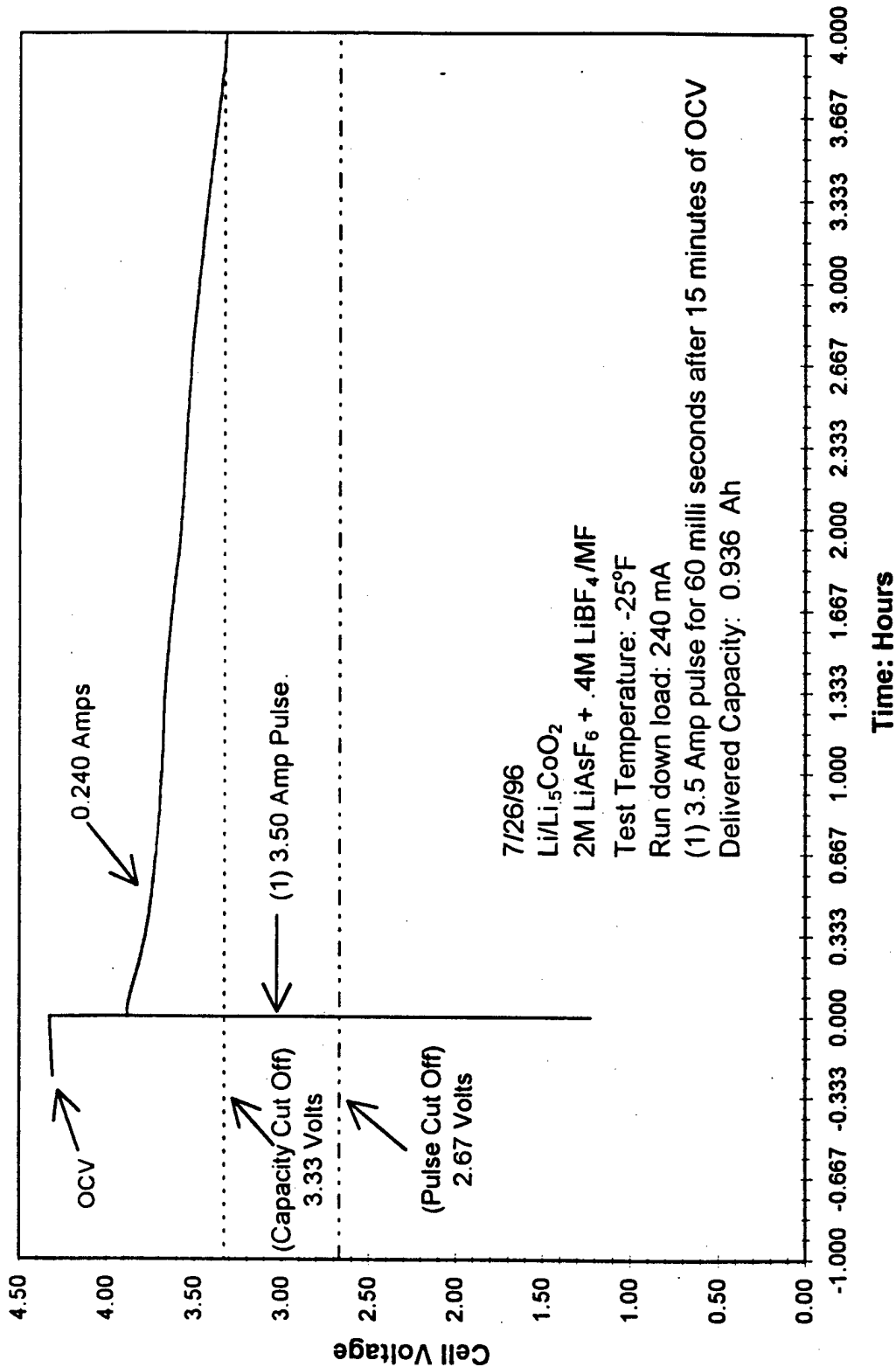
# Pulse and Capacity Run Down Profile, WAMH21

3 Month Storage @ -65°F

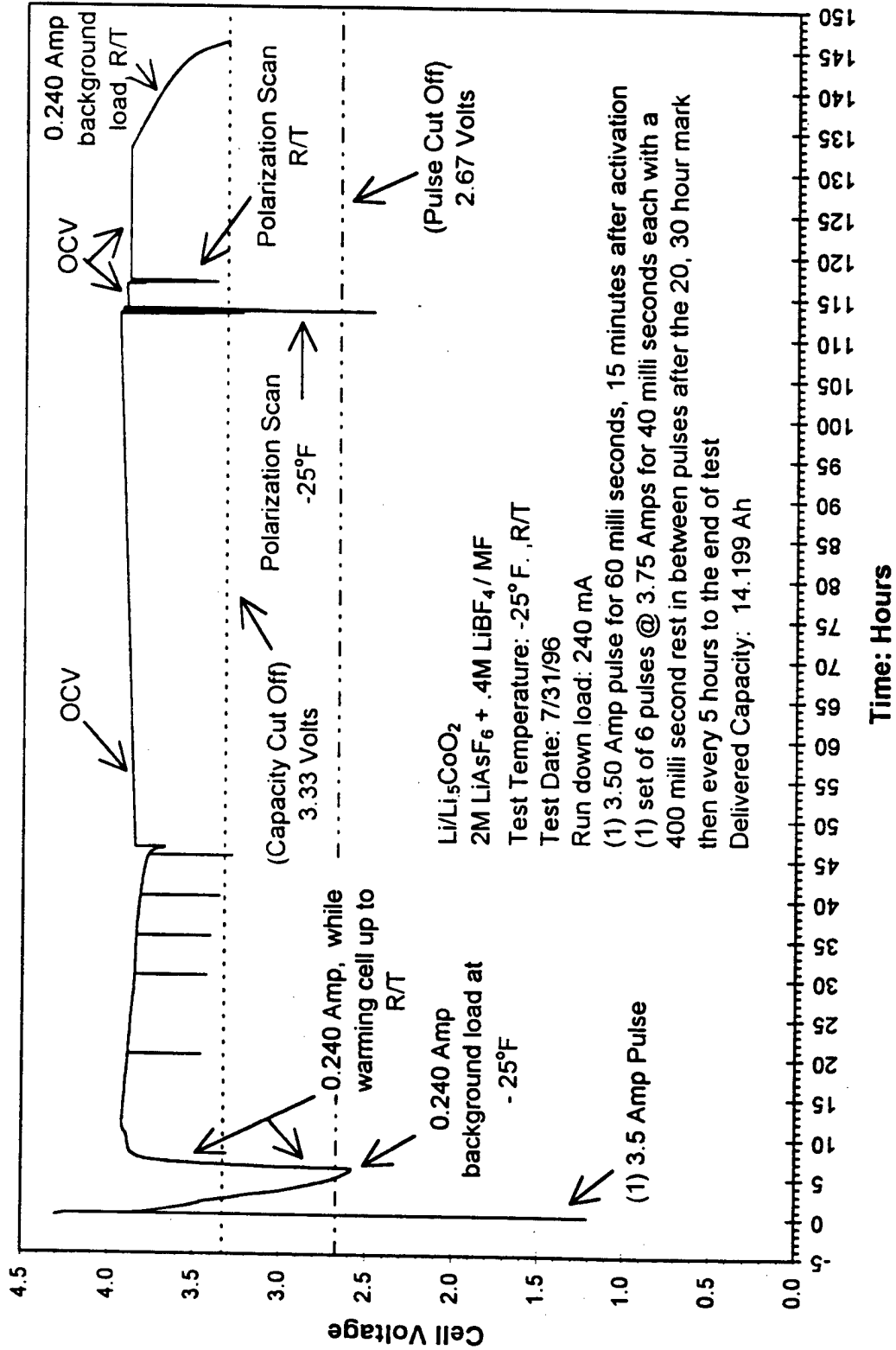


# Pulse and Capacity Run Down Profile, WAMH23

3 Month Storage @ +160°F



# Pulse and Capacity Run Down Profile, WAMH24 3 Month Storage @ R/T



**Appendix D**

**Safety Study Presentation of July 20, 1995**

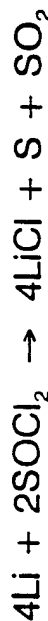
NSWC Option 7  
LiCoO<sub>2</sub> H-WAM Battery  
Safety Review  
20 July 1995

## Agenda

- Review electrochemical discharge comparing  $\text{SOCl}_2$  and  $\text{LiCoO}_2$  reactions
- Discuss hazard potential of the  $\text{LiCoO}_2$  electrochemical system
- Compare the potential for energy release of  $\text{LiCoO}_2$  battery with a  $\text{Li/SOCl}_2$  battery
- Review of design and manufacturing characteristics relevant to safety
- Discuss a  $\text{LiCoO}_2$  battery reaction to abusive external conditions
- Open Discussion

## REVIEW ELECTROCHEMICAL DISCHARGE COMPARING $\text{SOCl}_2$ AND $\text{LiCoO}_2$ REACTIONS

### Thionyl Chloride



- $\text{SOCl}_2$  is both electrolyte solvent and the active cathode material (solvent/oxidant).
  - Moderate build-up of pressure from  $\text{SO}_2$  during discharge.
  - Sulfur crystallizes (rhombic form) in the product solution.
  - Reacted electrolyte is a volatile substance<sup>1</sup>
  - Amount of elemental sulfur is proportional to depth of discharge.
- 
- ### Lithium Cobalt Dioxide
- $$y\text{Li} + \text{Li}_x\text{CoO}_2 \rightarrow \text{Li}_{x+y}\text{CoO}_2$$
- Cell is manufactured with cathode in a fully precharged state.
  - Ester based solvent for electrolyte solution (methyl acetate) in combination with  $\text{LiAsF}_6$  and  $\text{LiBF}_4$  salts.
  - There are no reaction products which contribute to increasing volatility with discharge.

<sup>1</sup>C.R. Schlaikjer, F. Goebel, N. Marincic, J. Electrochem. Soc., **126**, 513-522 (1979).

## $\text{SOCl}_2$ Intentional Abuse

Test Item:

MC3945 Reserve Li/SOCl<sub>2</sub> Battery

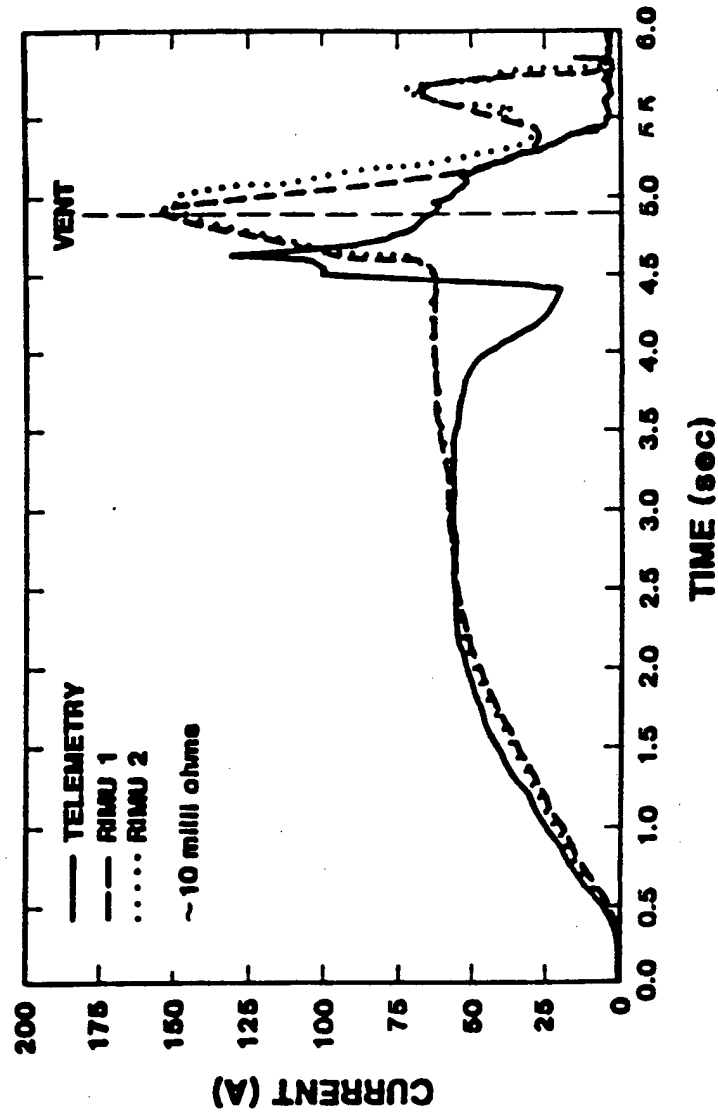
Test Conditions:

External Short ( $\approx 10 \text{ m}\Omega$ ) before activation

Results:

Violent case rupture  $\approx 4$  seconds after activation. Total current exceeded 400 amps ( $\approx 1000 \text{ mA/cm}^2$ ).

**3945 RLTC, S/N FH-09**  
**SHORT CIRCUIT TEST AT 40°C**



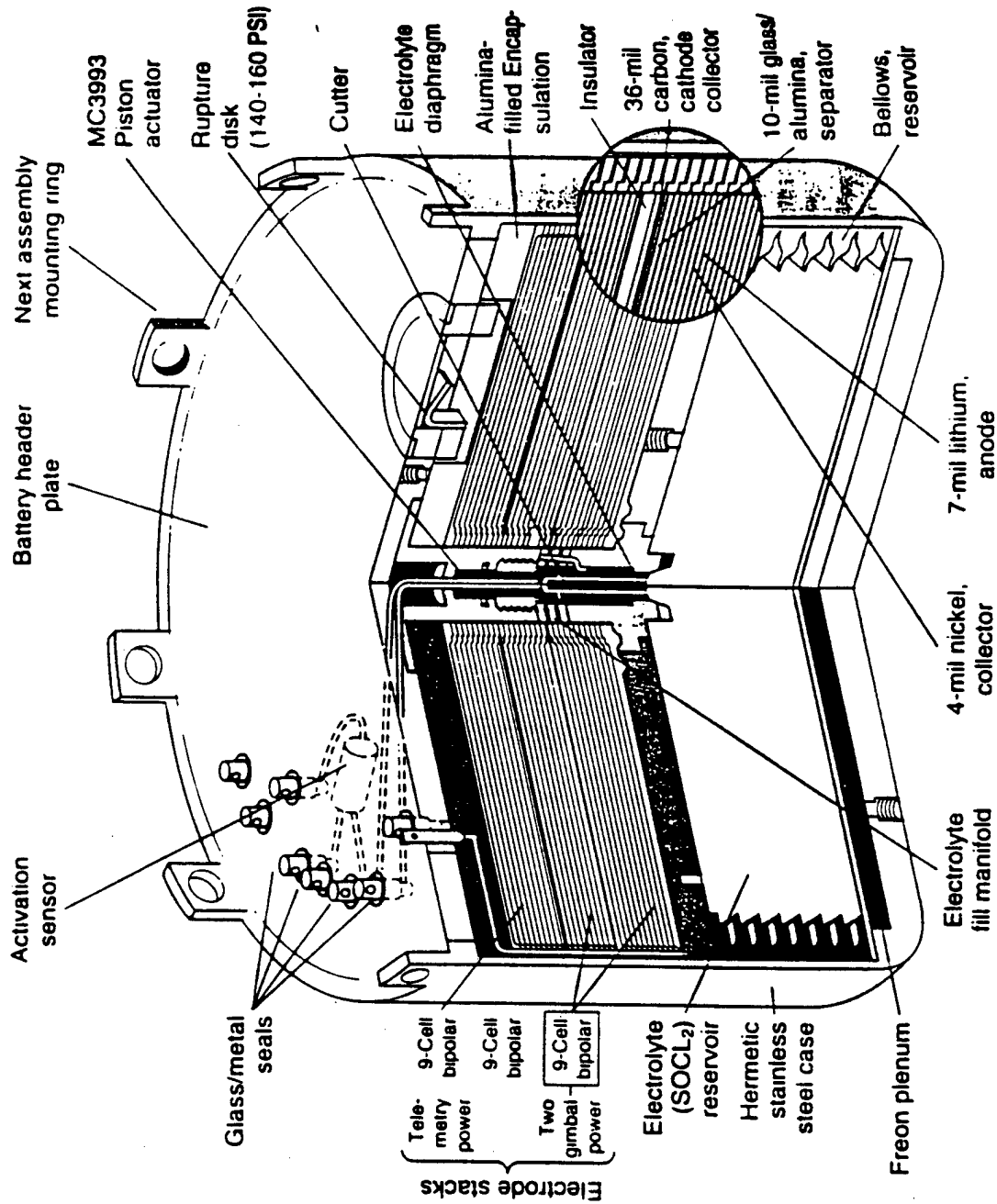
NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
Battery Safety Review  
20 July 1995

[M50720-1.wp] paw

ALLIANTTECHSYSTEMS



# MC3945 Reserve Battery



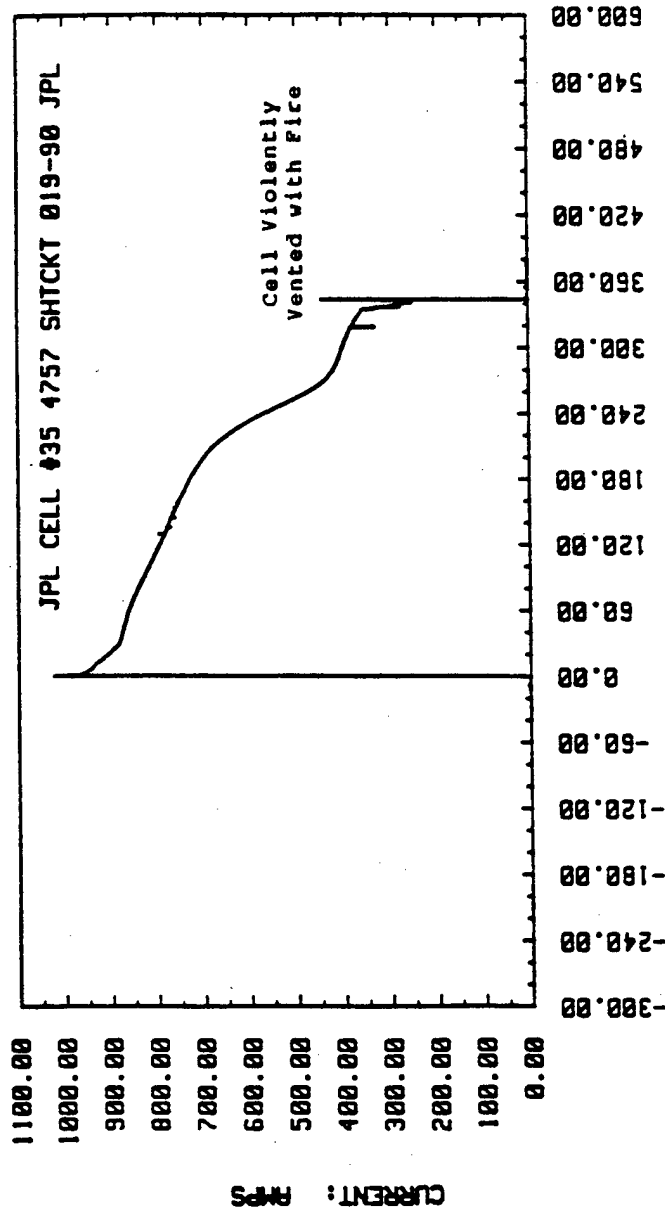
NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
 Battery Safety Review  
 20 July 1995

[M50720-1.wp]\*paw

ALLIANTTECHSYSTEMS

# $\text{SOCl}_2$ Intentional Abuse

Test Item: JPL 250 Ah (320 Ah)  $\text{SOCl}_2$  Active Cell  
 Test Conditions: Externally shorted fresh cell ( $\approx 2 \text{ m}\Omega$ )  
 Results: Violent venting/case rupture  $\approx 5$  minutes after shorting



TIME: SECONDS

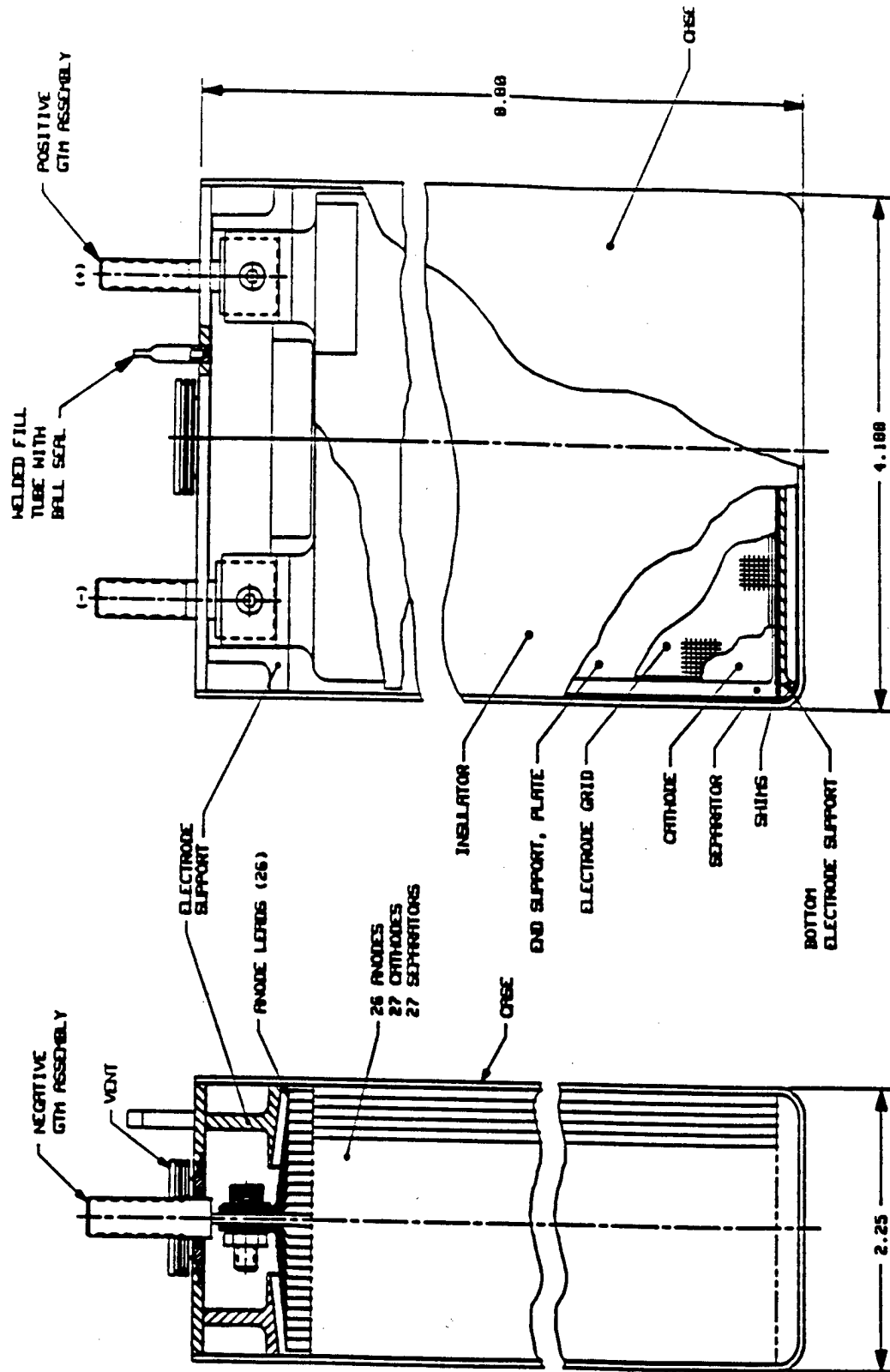
EXTERNAL SHORT CIRCUIT TEST AT +75°F

NSWC Option 7  $\text{LiCoO}_2$  H-WAM  
 Battery Safety Review  
 20 July 1995

[M50720-1.wp]\*paw



# JPL 250 Ah Cell



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
Battery Safety Review  
20 July 1995

[MS0720-1.wp]\*paw

ALLIANTTECHSYSTEMS

# Ziegler Seal "AA" Cells

Test Item:

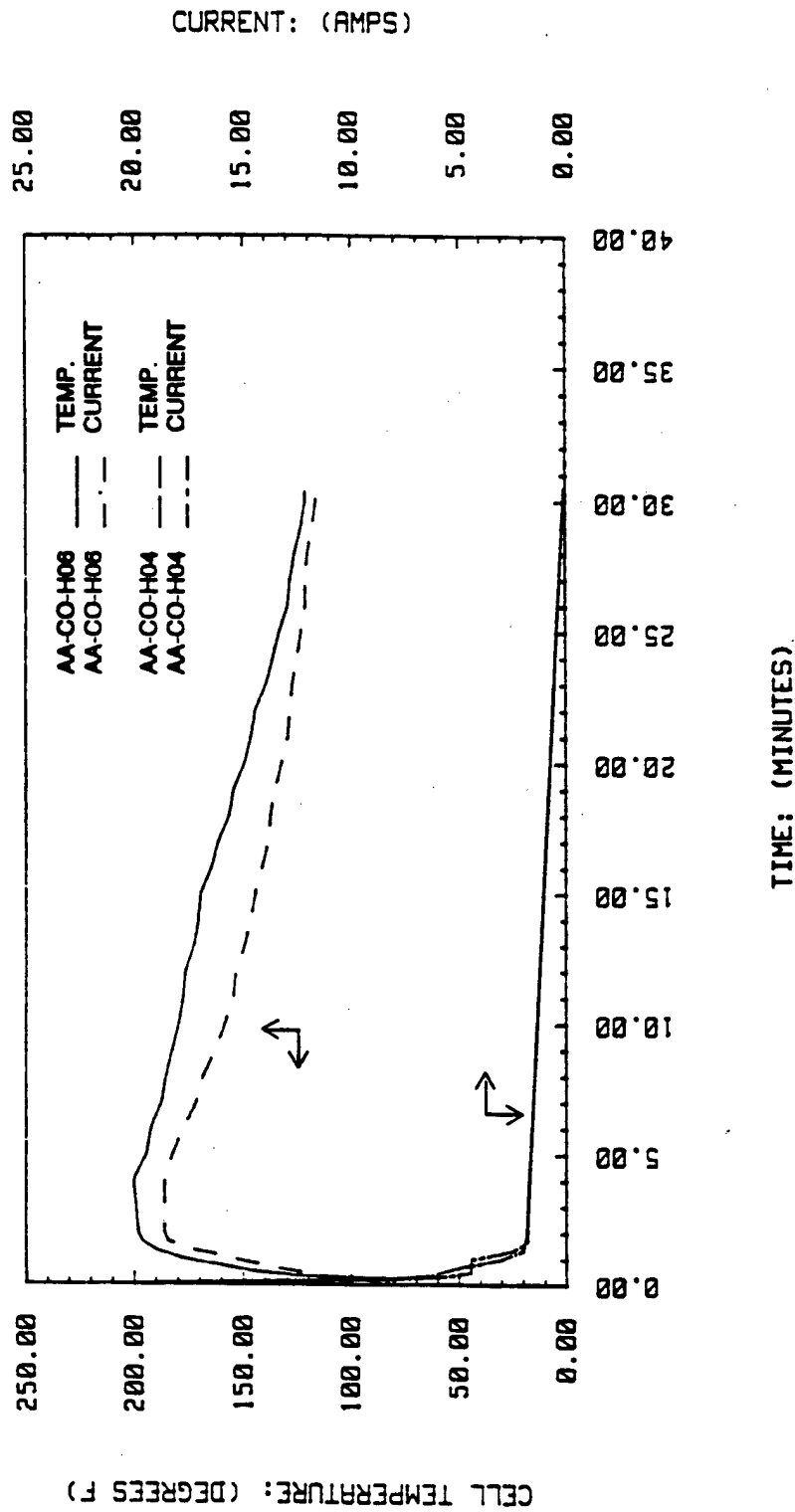
LiCoO<sub>2</sub> "AA" Cell (0.8 Ah)

Test Conditions:

Externally shorted charged cell

Results:

Measured peak current 20A (328 mA/cm<sup>2</sup>). Case temperature did not rise above 200°F. Cell remained intact. Vent did not open.



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
Battery Safety Review  
20 July 1995

[M50720-1.wp]\*paw

ALLIANTTECHSYSTEMS

# Differential Scanning Calorimetry

## Lithium Sample

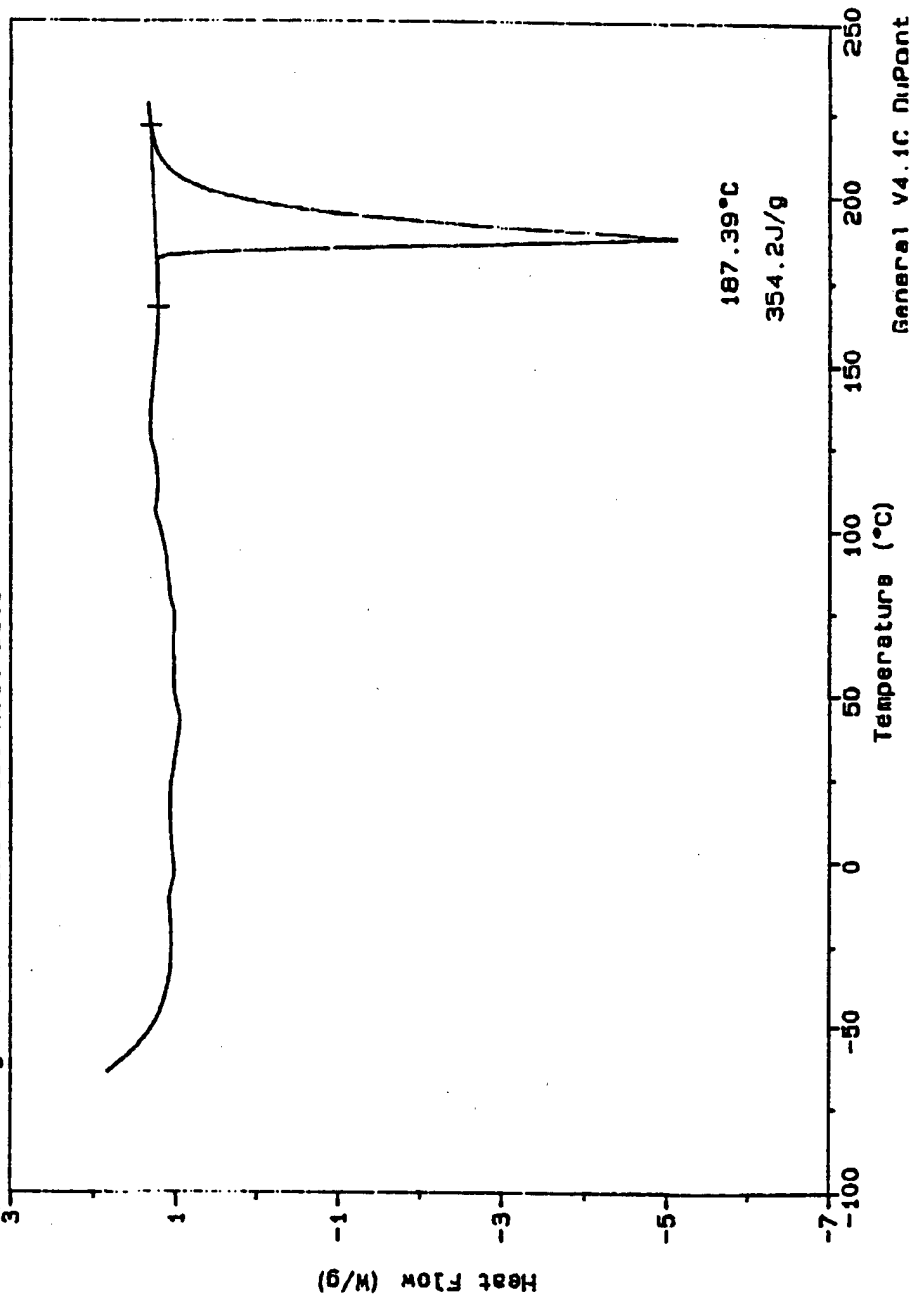
Sample: Lithium alone as received  
Size: 5.4600 mg  
Method: Program Scan 10.0°C/min  
Comment: Air Purge - PE SS Pans - 1st Heat Data -

DSC

File: C:\HMSCLI.100

Operator: J.Sosnowik MDSC 2910

Run Date: 7-Jul-95 09:02



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
Battery Safety Review  
20 July 1995

[M50720-1.wp]\*paw

ALLIANTTECHSYSTEMS

# Differential Scanning Calorimetry

LiCoO<sub>2</sub> Sample

Sample: LiCoO<sub>2</sub> As Received  
Size: 9.7500 mg  
Method: Program Scan 10.0°C/min  
Comment: Air Purge - PE Sealed SS Pans - Sealed in glove box -

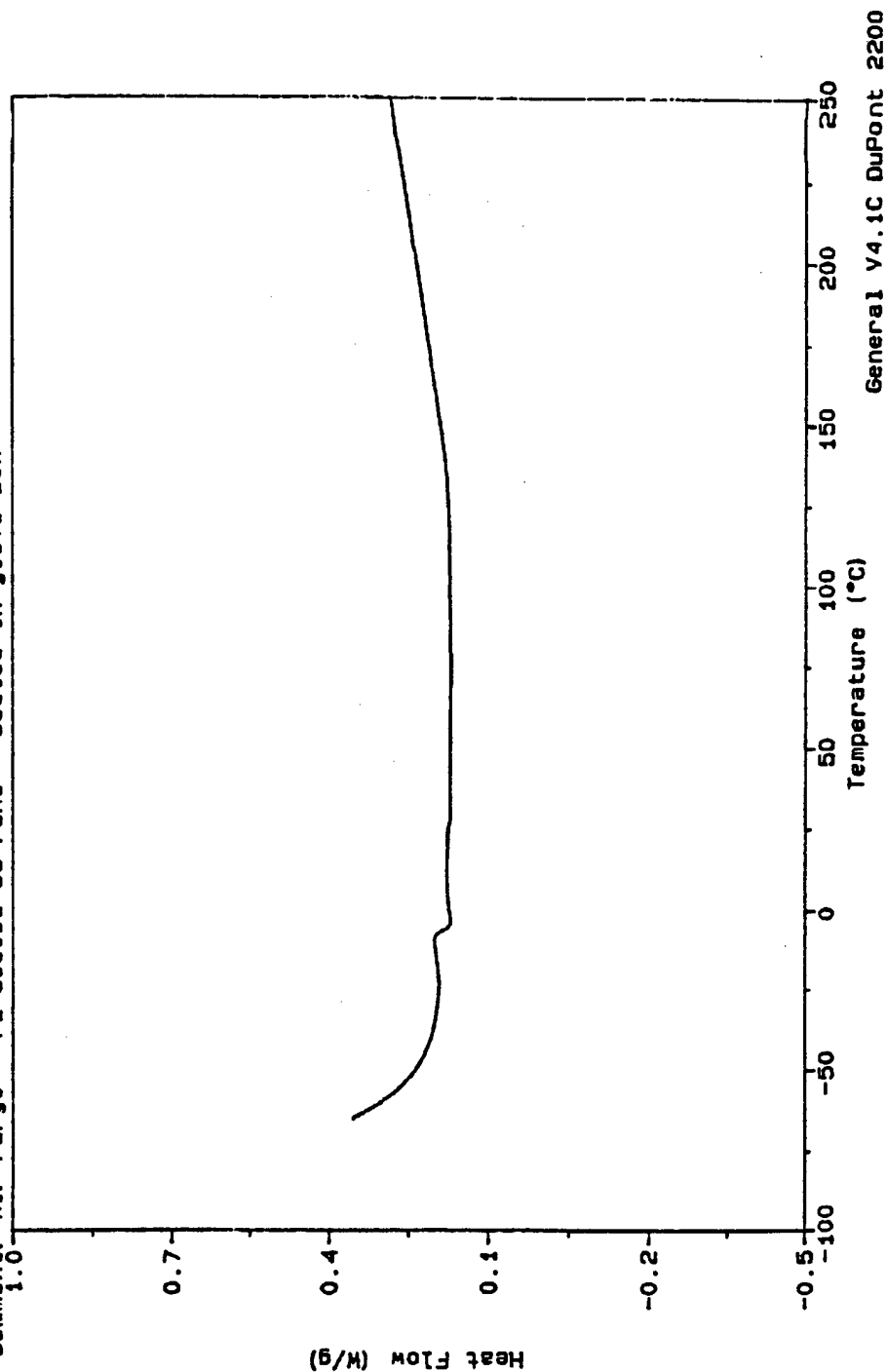
DSC

File: C:\HMSCLIC0.100

Operator: J.Sosnowik

MDSC 2910

Run Date: 6-Jul-95 11:04



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
Battery Safety Review  
20 July 1995

[M50720-1.wp]\*paw

ALLIANTTECHSYSTEMS

# Differential Scanning Calorimetry

## Methyl Acetate Electrolyte

Sample: MeAc/LiAsF<sub>6</sub> As Received  
 Size: 10.3100 mg  
 Method: Program Scan 10.0 °C/min  
 Comment: Air Purge - PE Sealed SS Pans - Sealed in glove box -  
 0.5

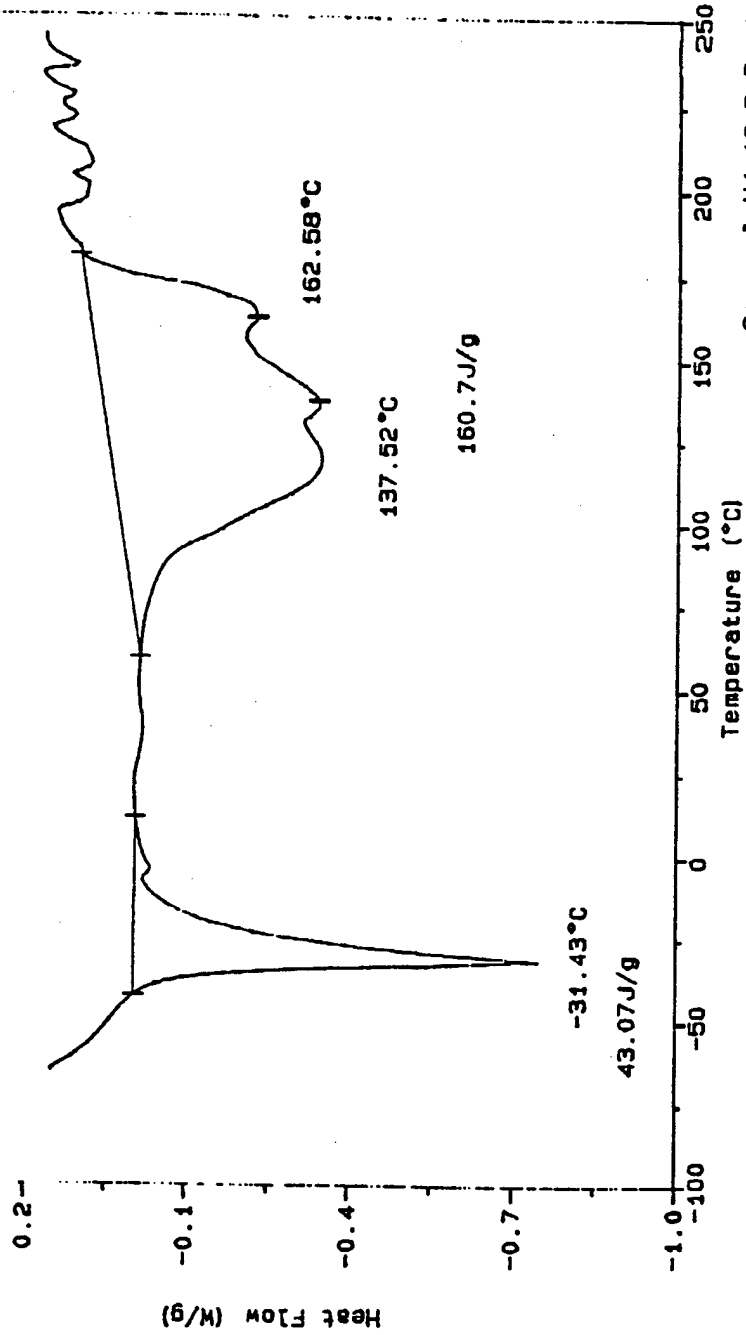
DSC

File: C:\HMDSCMEAC.100

Operator: J.Sosnowik MSC 2910

Run Date: 6-Jul-95 09:57

General V4.1C DuPont 2200



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
 Battery Safety Review  
 20 July 1995

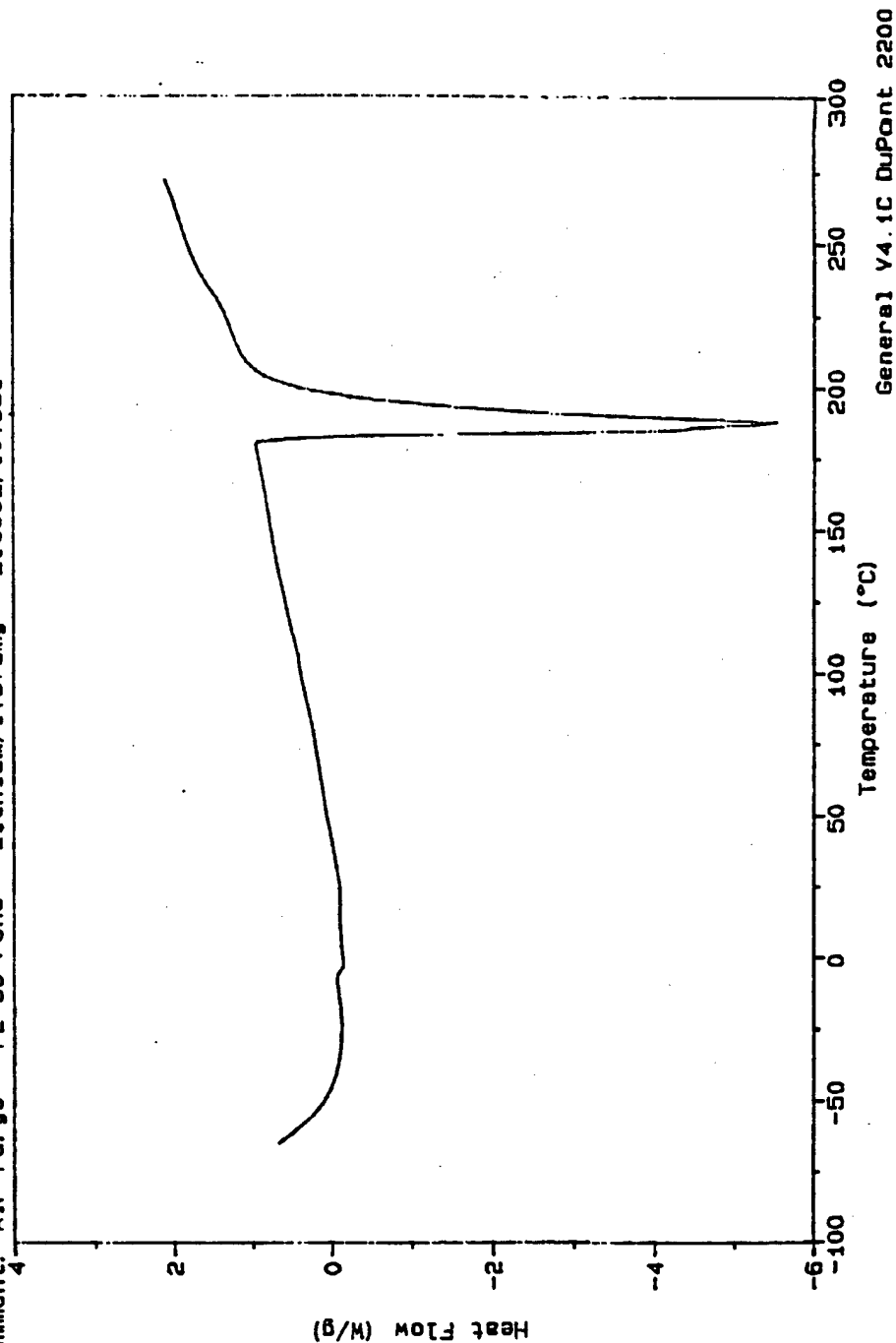
[M50720-1.wp] paw

ALLIANTECHSYSTEMS

# Differential Scanning Calorimetry

## Lithium/LiCoO<sub>2</sub> Sample

Sample: Lithium plus LiCoO<sub>2</sub>  
 Size: 1.8730 mg  
 Method: Program Scan 10.0°C/min  
 Comment: Air Purge - PE SS Pans - Lithium/1.873mg - LiCoO<sub>2</sub>/10.681 -  
**DSC**  
 File: C:\HMSCL\LI.100  
 Operator: J.Sosnowik MDSC 2910  
 Run Date: 7-Jul-95 13:15



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
 Battery Safety Review  
 20 July 1995

[M50720-1.wp]\*paw

ALLIANTECHSYSTEMS



# Differential Scanning Calorimetry

## LiCoO<sub>2</sub>/Methyl Acetate Electrolyte

Sample: LiCoO<sub>2</sub> \ MeAc/LiAsF<sub>6</sub> Mix  
 Size: 11.5690 mg  
 Method: Program Scan 10.0°C/min  
 Comment: Air Purge - PE SS Pans - LiCoO<sub>2</sub> 3.444mg / MeAc/LiAsF<sub>6</sub> 11.569mg -  
 0.8

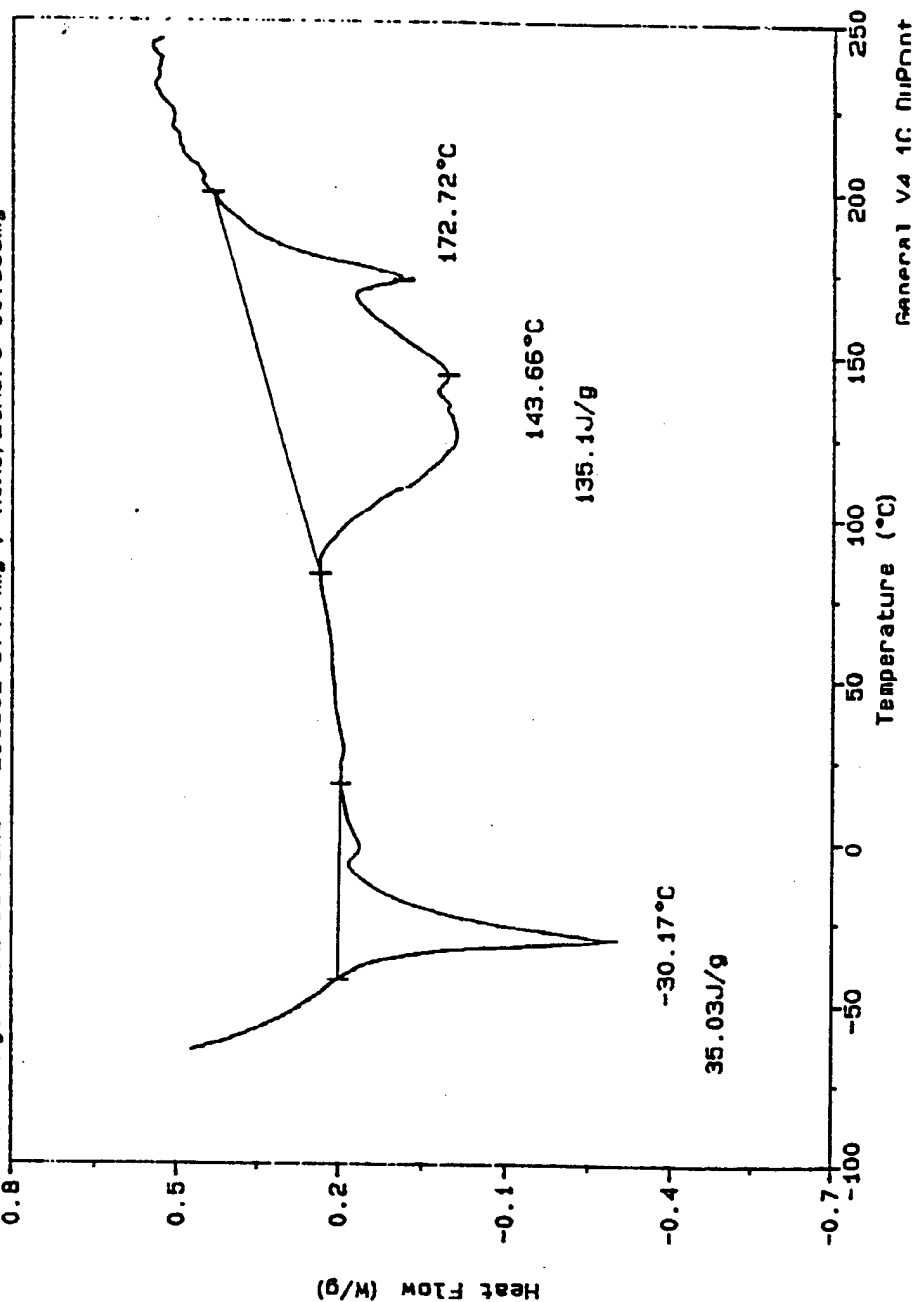
DSC

File: C:\HMDSCMIXA.100

Operator: J.Sosnowik MDSC 2910

Run Date: 6-Jul-95 12:23

MeAc/LiAsF<sub>6</sub> 11.569mg -



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
 Battery Safety Review  
 20 July 1995

[M50720-1.wp]\*paw

AMERICAN TECH SYSTEMS

# Differential Scanning Calorimetry

## Lithium/Methyl Acetate Electrolyte

NSWCCD-TR-98/005

Sample: Lithium plus MeAc/LiAsF6  
Size: 15.8700 mg  
Method: Program Scan 10.0°C/min  
Comment: Air Purge - PE SS Pans - Lithium/1.750mg - MeAc/15.870mg -

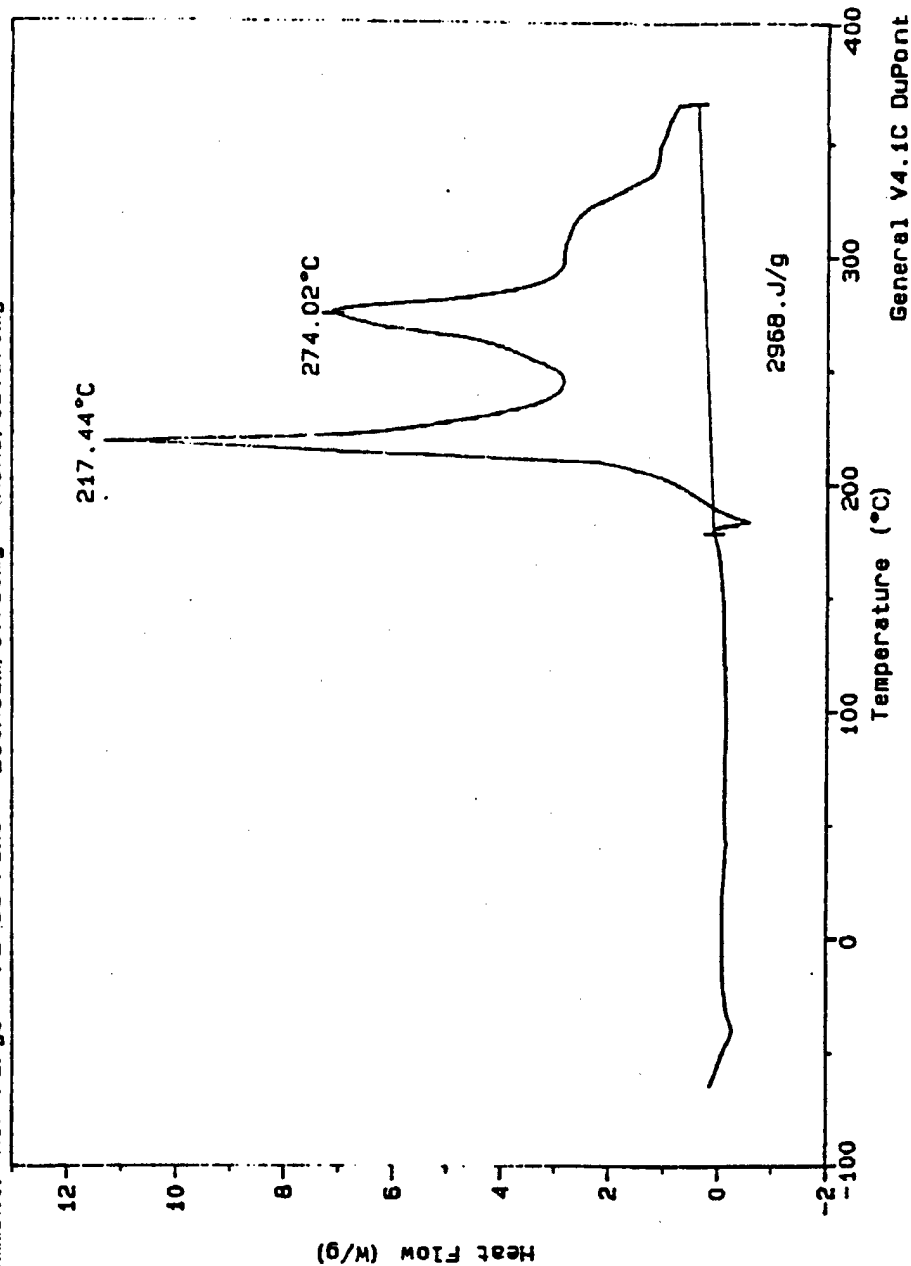
DSC

File: C:\HMSCLINE.100

Operator: J.Sosnowik

MDSC 2910

Run Date: 7-Jul-95 10:07

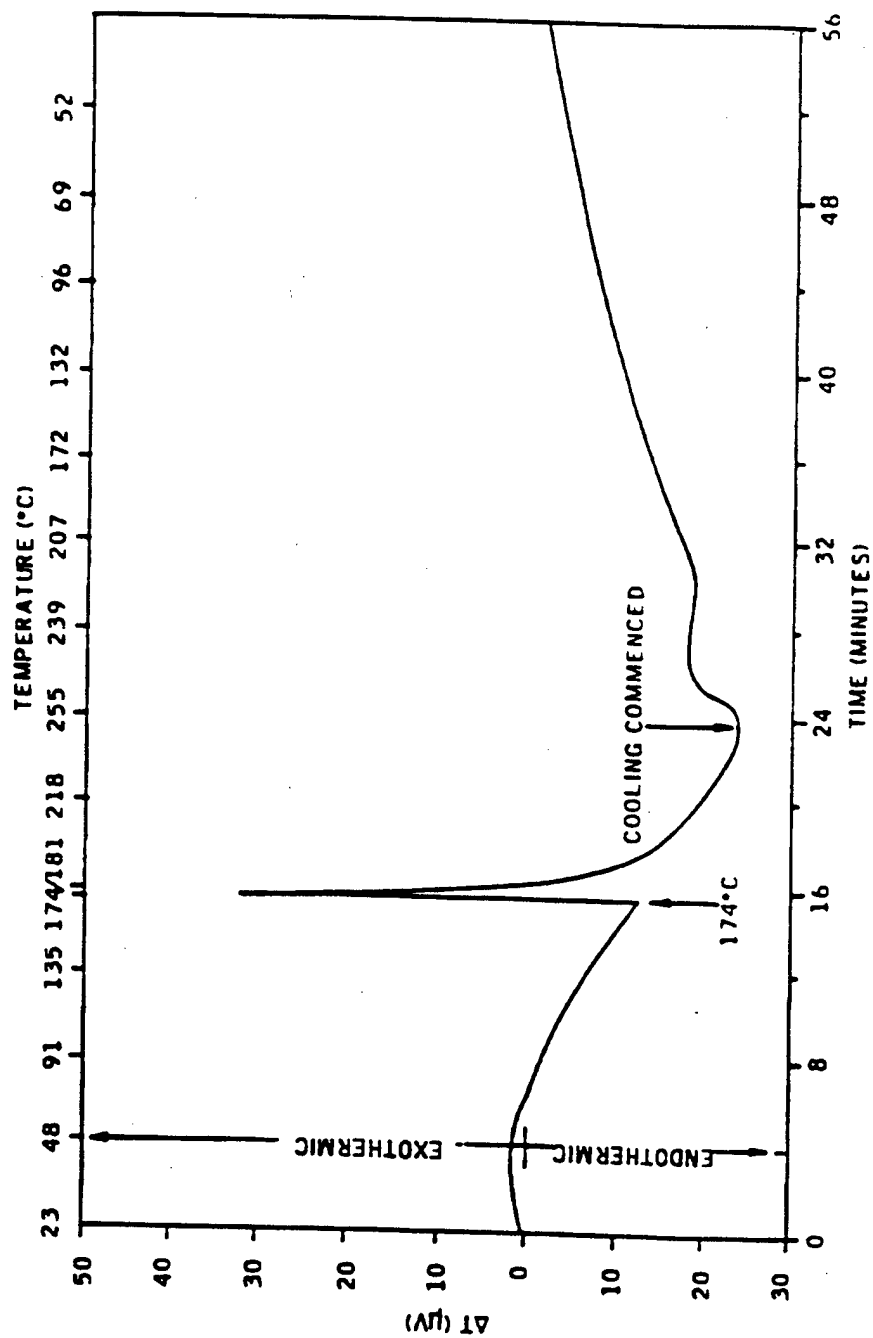


NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
Battery Safety Review  
20 July 1995

[MS0720-1.wp]\*paw

ALLIANTTECHSYSTEMS

# Part of a Thermogram from DTA of a Sample Containing LI (0.8 mg) and S (2.30 mg)



NSWC Option 7 LiCoO<sub>2</sub> H-WAM  
Battery Safety Review  
20 July 1995

[M50720-1.wp]\*paw

ALLIANTTECHSYSTEMS

## Differential Thermal Analysis Results

Sample (mg)	Temperature of lithium fusion endotherm (°C)	Temperature and description <sup>a</sup> of exotherms			
		Under 300°C	300-360°C	360-380°C	Over 380°C
Li (0.8) + S (2.3)	--	174, 1, sh	--	--	--
Li (5.8) + SOCl <sub>2</sub> (2.1)	179	--	356, 1, sh	--	--
Li (4.8) + SO <sub>2</sub> Cl <sub>2</sub> (6.6)	178	252, s, b	357, 1, sh	362, 1, sh	408, s, b
Li (4.8) + S <sub>2</sub> Cl <sub>2</sub> (14.0)	180	Upward drift	357, m, sh	370, s, sh	390, 1, sh
Li (3.5) + S (6.5) + SOCl <sub>2</sub> (12.0)	180	Upward drift, started 280°C	334, 1, sh	--	--
Li (8.0) + S (12.8) + SO <sub>2</sub> Cl <sub>2</sub> (16.0)	179	293, 1, sh	334-348 four s, sh	--	--
Li (3.4) + S (11.3) + S <sub>2</sub> Cl <sub>2</sub> (11.8)	178	250, s, b	--	--	390, 1, sh
Li (2.0) + Cathode Mix (5.0)	174	--	--	--	429, 1, sh
Li (10.3) + Glass (4.1)	176	--	--	--	587, s, sh

<sup>a</sup> Size: s = small, m = medium, l = large  
Shape: b = broad, sh = sharp

# DESIGN FEATURES AND MANUFACTURING CHARACTERISTICS ENHANCING BATTERY SAFETY

## Design

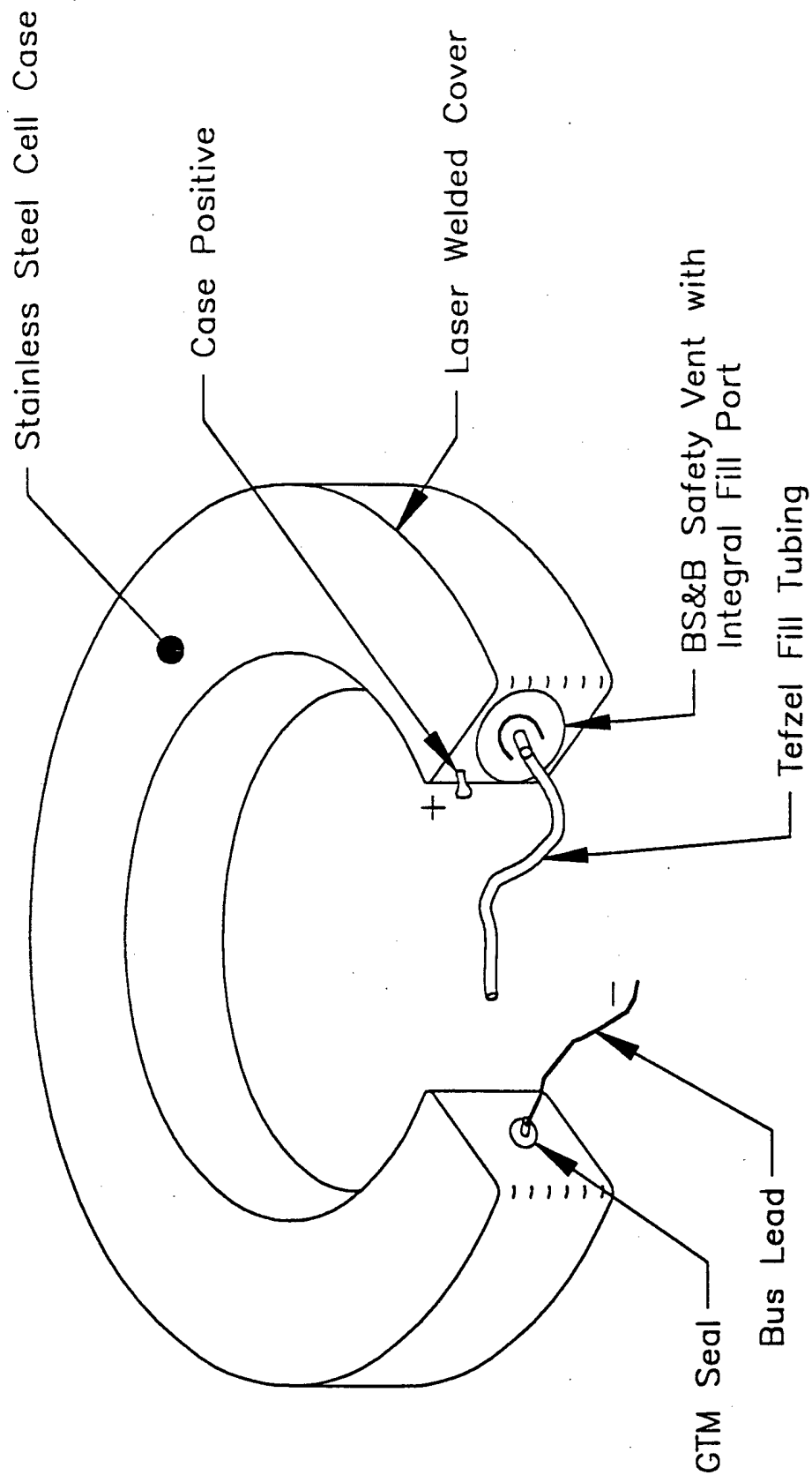
- Safety vents (scored diaphragm type)
  - one per cell
  - one per battery housing
- Shut down separator - microporous PP/PE/PP
  - Not glass as used in  $\text{SOCl}_2$ . Lithium and glass reacts at  $207^\circ\text{C}$ .
- Fused links in cell leads.
- Electrolyte flooded cells.
- Independent electrolyte reservoirs for each cell. No intercell leakage. Hermetic metal bellows reservoirs.
- Flame arrestor matting outside safety vents.
- Current collector grids are chemically etched - no burrs.

## Manufacturing

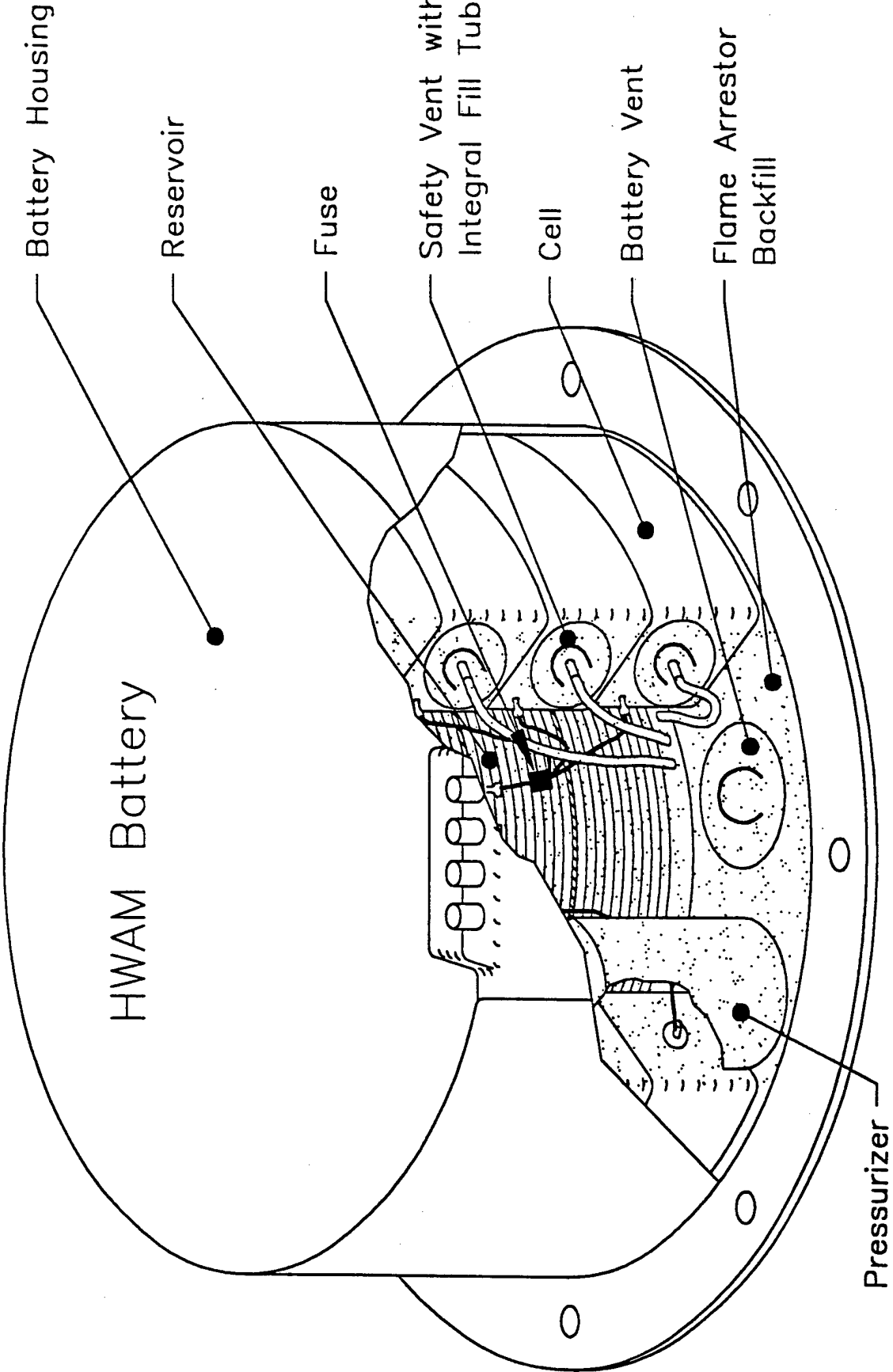
- Offset electrode edges with separators enveloping and heat sealed around every electrode plate.
- Stack alignment keyed to solid separator edges via assembly tooling.
- No dendrites in reserve state because cathode is precharged before assembly, new lithium metal anodes are assembled in reserve cell.

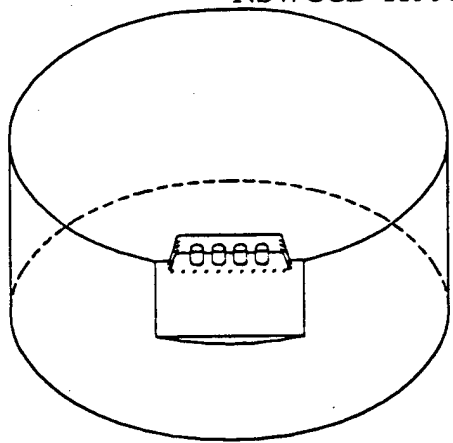
# Individual Cell Case

NSWCCD-TR-98/005

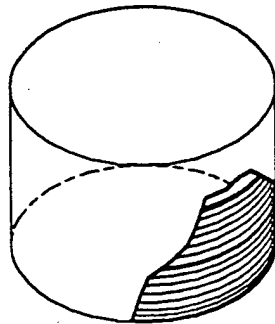


07/14/85 AJS/CLK  
FILE: ISOHWA2.DWG

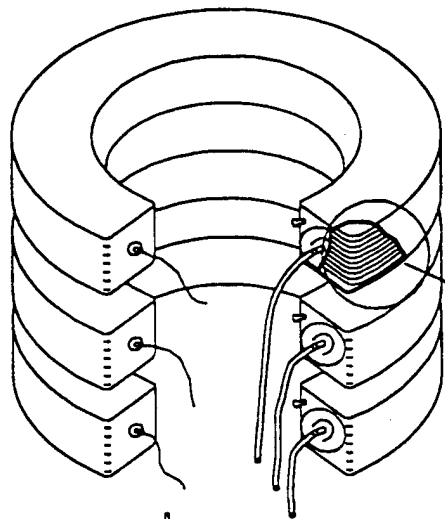




Battery Housing

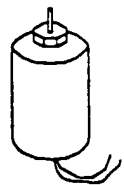
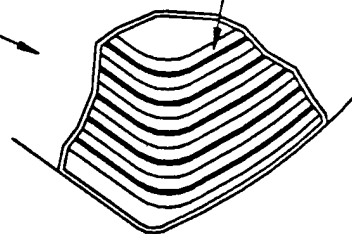


Reservoir

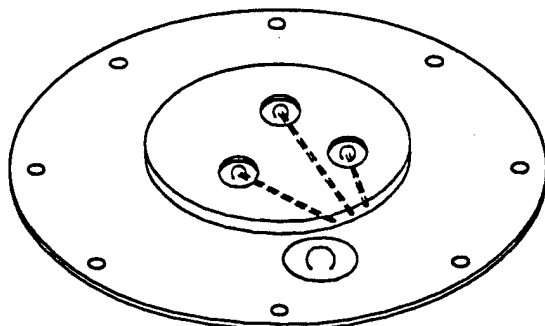


(3) Cells

Electrodes



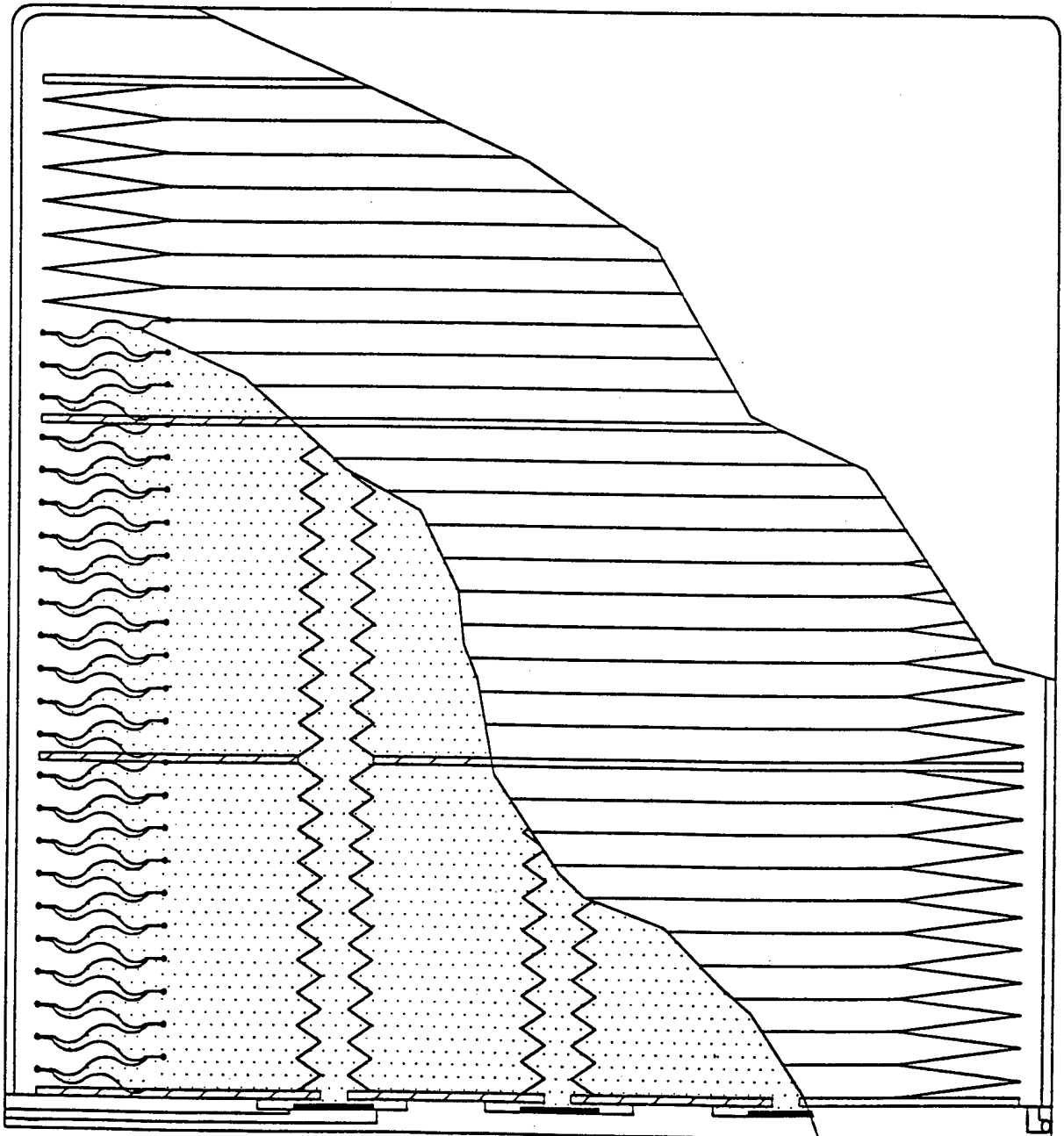
Pressurizer



Mounting Flange and  
Bottom Bulkhead

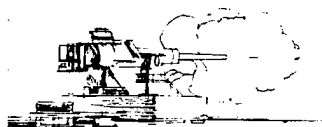


# Cross Section of HWAM Reservoir



07/19/95 AJS/CJK  
FILE: HWAM4.DWG

**Appendix E**  
**Specification Sheets for Ordnance Batteries**



## Ordnance Batteries

### Electrochemical Variations Give Two Dimensionally Similar Batteries Vastly Different Capacities

Electrochemical flexibility has allowed PSC to produce two electrically and physically interchangeable batteries with very different capacities for the U.S. Army's FASCAM (Family of Scatterable Mines) project. Both reserve batteries are small and low-rate, and they offer long life relative to their size.

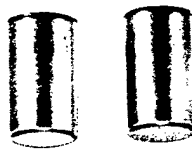
In both batteries, electrolyte is held in reserve in a glass ampul until a mechanical, electrical, or explosive impulse fractures the glass to release the electrolyte and activate the battery. This system gives an ambient shelf life of more than 20 years, yet allows rapid rise to full power and fresh cell capacity.

The first of the two, the G2666, has been in high-volume production at Honeywell since 1978. It offers a capacity of 100 mAh, and is based on  $\text{Li}/\text{V}_2\text{O}_5$  electrochemistry. Product reliability is greater than .9993 at 98 percent confidence.

More recently designed and now in pilot production, the G2666B1 uses  $\text{Li}/\text{SOCl}_2$  electrochemistry to produce a capacity of 280 mAh. Together, the two batteries prove the versatility of the variety of electrochemical configurations available from PSC's design teams.

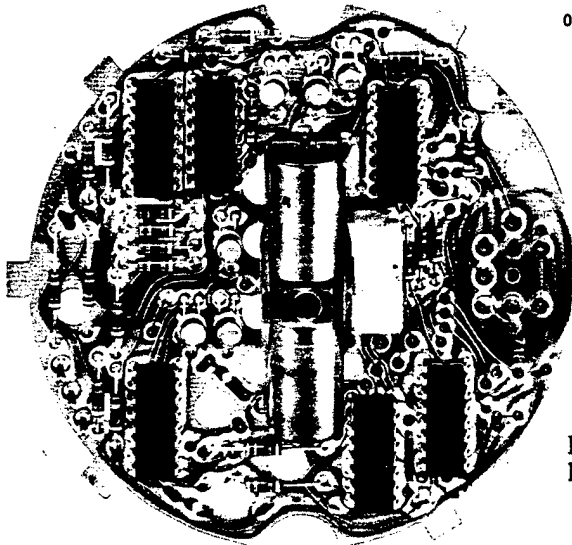
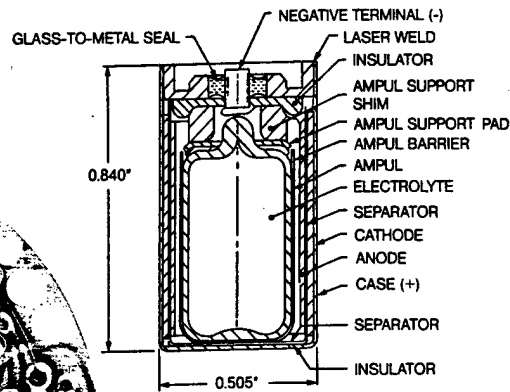
### Specifications

	Model No. G2666 Chemistry $\text{Li}/\text{V}_2\text{O}_5$	Model No. G2666B1 Chemistry $\text{Li}/\text{SOCl}_2$
<b>Performance</b>		
Open circuit voltage:	3.4 volts	3.6 volts
Voltage under load:	3.3 volts at 0.5 mA/plateau #1	3.6 volts with 65,000 ohm load
Rated capacity:	3.1 volts at 0.5 mA/plateau #2 100 mAh to a 2.5 volt cutoff at 0.5 mA load at 72°F	280 mAh to a 2.5 volt cutoff at 0.49 mA load at 72°F
Energy density (at rated load):	2.06 Whr/in <sup>3</sup> , 0.122 Whr/cc 27.5 Whr/lb, 0.061 Whr/g	6.13 Whr/in <sup>3</sup> , 0.37 Whr/cc 89.1 Whr/lb, 0.20 Whr/g
<b>Physical Characteristics</b>		
Diameter:	0.50 inches	0.50 inches
Length:	0.84 inches	0.84 inches
Weight:	0.18 oz	0.18 oz
Volume:	0.16 inches <sup>3</sup>	0.16 inches <sup>3</sup>
Positive terminal:	Glass-to-metal seal with 52 alloy pin	Glass-to-metal seal with 52 alloy pin
Case material:	316L Stainless Steel	316L Stainless Steel
<b>SAFETY FEATURES</b>		
Reserve:	Electrolyte stored in glass ampul. Both cells inactive during storage.	



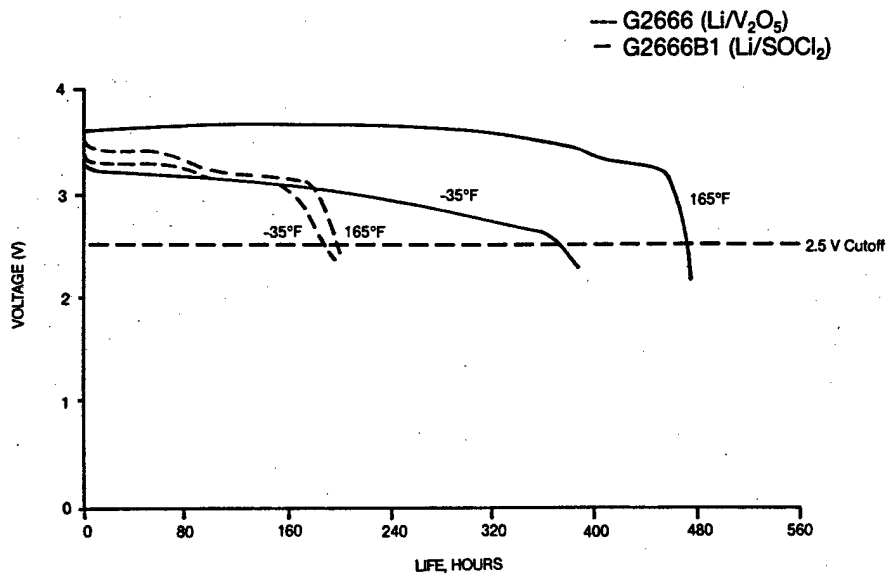
G2666 Cells and Ampuls

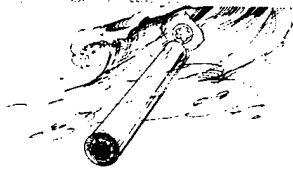
**Lithium/Thionyl  
Chloride Reserve  
Cell Model G2666B1**



Batteries mounted on  
FASCAM pc board.

**Output Capacity Comparison for G2666  
and G2666B1 Cells at .5 mA**





## Underwater Mines/ Buoy Batteries

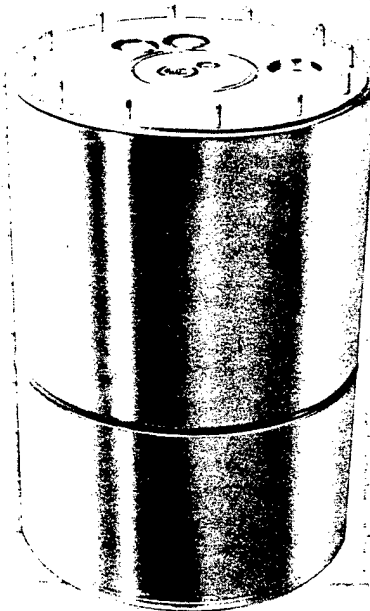
### 4000 Watt Battery Employs Standard Technology

The Model G3070A2 is an expendable, high power, remotely activated multicell lithium battery, containing two electrically isolated voltage sections. The low power section operates continuously at 71 watts, while the high power section operates at 4000 watts. Testing has demonstrated the battery can operate at pulses to 200 amps, providing pulse power outputs of 10,000 watts.

Maintaining the battery's reserve integrity is a major safety feature. Until it is electrically initiated, the battery will not activate during handling, shipping, or storage. For test purposes, the battery was activated and allowed to stand on open circuit for 90 days. During the test there were no safety related episodes, and the battery retained 85% of fresh discharge capacity. In the event the battery is subjected to an abusive condition, it contains a series of venting mechanisms.

#### PHYSICAL CHARACTERISTICS

Diameter:	11.5 inches
Length:	17.0 inches
Weight:	140 pounds
Activation Method:	Electrically initiated Squib assembly
All Fire Current —	5 amps, 10 msec pulse
No Fire Current —	1 amp-1 watt 5 minutes at 225°F
Oper. Temp. Range:	-40°C to +60°C
Case Material:	Stainless Steel



G3070A2 Battery

## Specifications

Model No. G3070A2  
Battery

Low Power Section  
Li/SOCl<sub>2</sub> Reserve/Series  
Connected Multiplate Cells

High Power Section  
Li/SOCl<sub>2</sub> Reserve/Series  
Connected Multiplate Cells

### Performance

Number of Cells  
Open Circuit Voltage:  
(Activated)  
Voltage under load:

3 cells  
11.0 volts

18 cells  
66.0 volts

Rated Capacity:

10.2 volts 7 amps  
at 20°C  
57 Ahr at 7 amps to  
8.0 volts at 20°C  
71.4 watts continuous

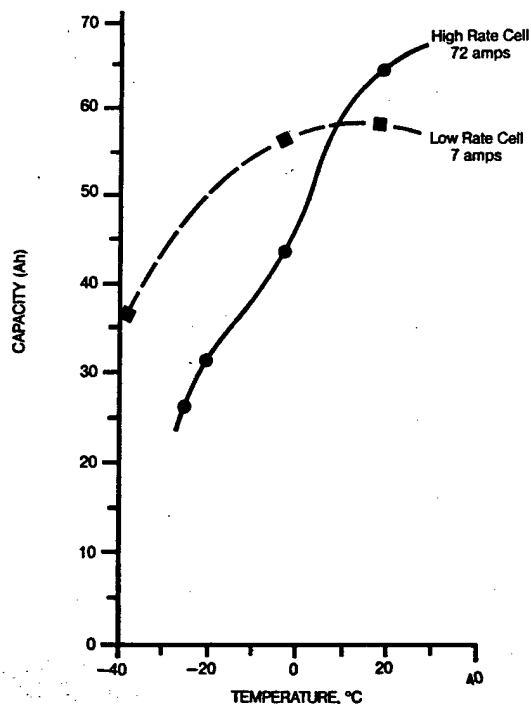
55.8 volts 72 amps  
at 20°C  
65 Ahr at 72 amps  
to 47.3 volts at 20°C  
4018 watts, pulses to  
200 amps

### Safety Features

Reserve:

- Electrolyte stored in stainless steel reservoir
- Battery case and reservoir vents
- Temperature monitoring sensor
- Cell and cell stack voltage monitoring leads
- Fully shielded actuator firing leads

**G3070A2 Cell Capacity  
at Various Temperatures**



## Physically Similar, High Power, Reserve Cells, Offer Performance Alternatives

The Low and High Power performance of the G3070A2 Reserve Battery sections (pages 4 and 5) demonstrate the wide current carrying capability of its cells.

These two physically similar, remotely activated cells are tailored for low rate (7 amps) or high rate (200 amp pulses) performance. Differing only in cell height and capacity, as a result of one less set of electrodes, the two cells offer corresponding rate carrying ability.

They are the baseline cells for the G3070A2 battery and allow for flexibility in battery design through series/parallel configurations.

As presented in the specifications, the two cells have the same inside and outside diameters. However, they differ in height (0.06 inches), which results in a corresponding decrease in rate carrying ability of the low rate cell.

## Specifications

Model No. G3070A2  
Low Rate Reserve Cell  
Chemistry Li/SOCl<sub>2</sub>

Model No. G3070A2  
High Rate Reserve Cell  
Chemistry Li/SOCl<sub>2</sub>

### Performance

Open Circuit Voltage:  
Voltage under load:

3.67 volts (activated)

3.40 volts 7 amps at  
20°C

Rated Capacity:

57 Ahr at 7 amps  
to 2.67 volts at 20°C

3.67 volts (activated)

3.10 volts 72 amps at  
20°C

65 Ahr at 72 amps  
to 2.63 volts at 20°C

### Physical Characteristics

Max Diameter: OD

11.22 inches

Max Diameter: ID

2.65 inches

Max Height:

0.35 inches

Cell Weight w/electrolyte:

1310 grams

2.89 lbs

Case Material:

Stainless Steel

11.22 inches

2.65 inches

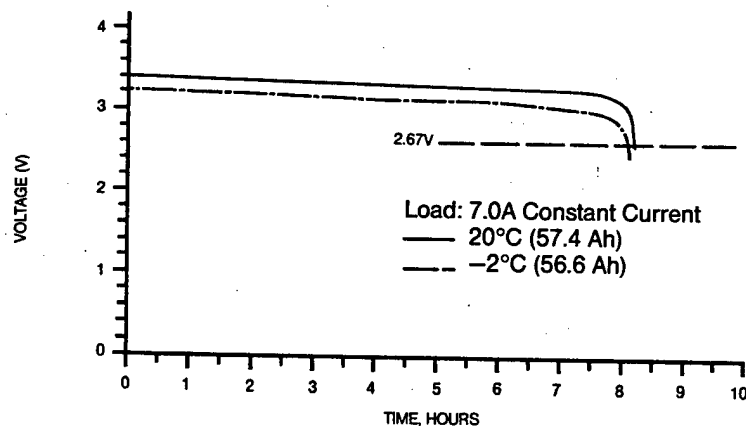
0.41 inches

1485 grams

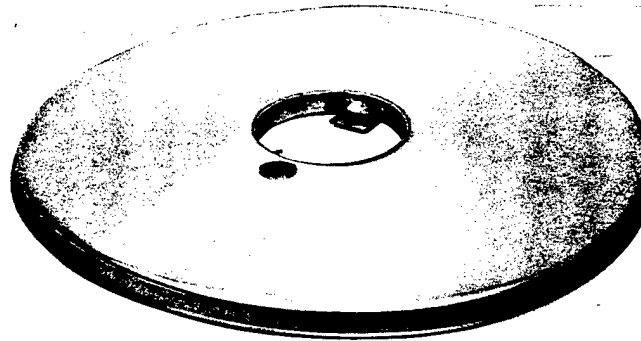
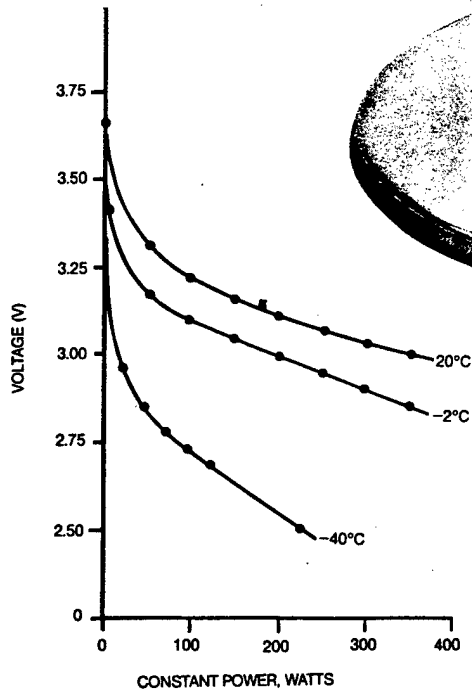
3.27 lbs

Stainless Steel

## G3070A2 Low Rate Cell Discharge Profile

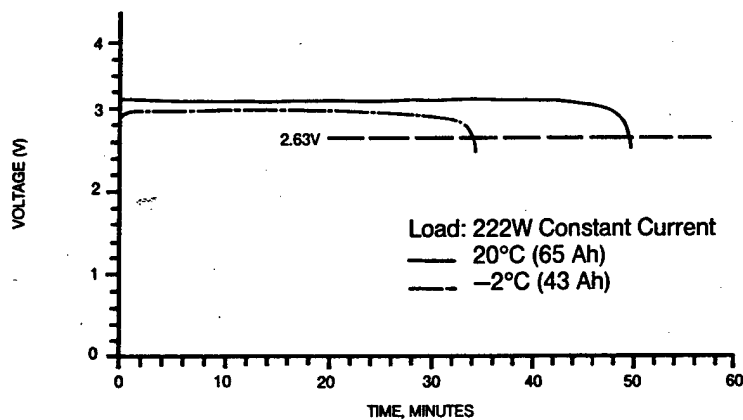


### Voltage Characteristics of G3070A2 High Rate Cell at Various Temperatures and Powers



G3070A2 Cell

### G3070A2 High Rate Cell Discharge Profile





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COMMANDER		ATTN CODE E232	1
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2800 POWDER MILL RD		DAHLGREN VA 22448-5100	
ADELPHI MD 20783-1197		COMMANDER	
COMMANDER		ATTN CODE E35	1
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US ARMY RESEARCH LAB		17320 DAHLGREN RD	
2800 POWDER MILL RD		DAHLGREN VA 22448-5100	
ADELPHI MD 20783-1197		COMMANDER	
ATTN OTS TYLER X MAHY	1	ATTN CODE N742 (GIDEP)	1
U S GOVERNMENT		NSWCDD	
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AFRL/PRPB		ATTN LIBRARY	1
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		ELMWOOD PARK NJ 07407	
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PO BOX 1625			
IDAHO FALLS ID 83415-3830			
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KIRTLAND AFB NM 87117-6008			
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